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ENGINEERING IN SOIL AND WATER CONSERVATION

By T. B. Chambers [1]

THE job of the engineer in a soil and water conservation program is to apply sound principles and works on agricultural lands. The same fundamentals of hydraulics, mathematics, physics, mechanics, and other sciences are as necessary here as in larger and more intricate structures, but their application requires new thinking and the development of new techniques. There is a woeful lack of relevant and essential agricultural engineering data, the urgent need for which becomes immediately manifest in actual field experience.

Soil conservation engineering structures are none the less vital because they are of small size. Often their very smallness makes them much more complex and difficult to treat. Especially is this true when the economics of the situation is considered. Small works scattered over large areas entail proportionately larger costs for planning and supervision. The balancing of such costs with the usual modest income from the farm is a problem to tax the ability of the most able engineer in devising methods of application, developing techniques, and standardizing practices.

The existing system of land tenure requires the conservation program to be applied on a farm unit basis. The needs of the land for conservation, the cropping practices followed, and the ability of the farmer or rancher to finance the necessary measures, must all be considered by the engineer in advancing his part of the program. Numerous other factors of an inherent nature, such as soil characteristics, slope, climatic features, run-off, and adaptable vegetation, also have a bearing. The engineer who has a good agricultural background is usually best qualified to cope with these problems.

To give proper weight to these factors and apply corrective measures to each piece of land in accordance with its needs and adaptability, the Soil Conservation Service employs a group of technicians, including agronomists, soil scientists, farm management specialists, foresters, and engineers, whose task it is to examine the problem as a group and together to work out a coordinated program. Thus, the engineer fits his contributions into a pattern of which he is but one of the designers.

There are certain fundamental methods of control on cultivated land which I feel should be set forth here. By an analysis of each method the engineer can more readily determine what he must do to accomplish the desired objectives. These fundamental methods are: (1) The improvement of the textural characteristics of the soil; (2) the use of vegetation to bind the soil in place and, (3) the interception and diversion or storage of surface run-off.

I am of the opinion that these three items constitute the main field in which the engineer should concentrate his efforts and clearly define his responsibilities in the conservation program. The complete and intensive application of these fundamental methods, if properly coordinated, should ensure both the maximum control of soil losses caused by wind or water, and the conservation of water in the arid and semiarid regions.

The improvement of the soil's physical condition, especially where long continued abuses have depleted organic matter and mineral nutrients, is of first consid-

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eration. The rate of absorption and the quantity of rainfall storage can be greatly increased by the addition of humus and the action of plant roots, as has been proved on the soil erosion experiment stations. The methods chiefly favored are agronomic; they consist of crop rotations, use of legumes and grasses, fertilization, liming, etc. These practices need not be discussed here, but they are of extreme value to the engineer since by their use more water is stored in the ground. The engineer knows that every drop that can be made to soak into the ground means just that much less surface water with which to contend. In regions where wind erosion is the main problem, increased absorption of moisture helps to produce a protective cover and prevent soil losses.

In addition to the agronomic practices usually applicable, certain mechanical measures may be used. Deep tillage is adaptable to some soils and, by breaking up tight subsurface structures, may appreciably increase the rate of infiltration and storage capacity. Improved tillage practices, either by special machines or by timely operation in relation to season or the soil's moisture content, may be useful. A study of the condition may suggest to the engineer other mechanical practices that are adaptable, but the essential thing to him is that he do all that can be done to provide, by decreased run-off, increased protection to any structural measures.

The use of vegetation to bind the soil in place and retard surface flow is a practical conservation measure generally understood and extensively used by the agronomist and forester in controlling water and wind erosion. Such practices as strip cropping, pasture and range improvement, long rotations to include several years of erosion-resisting crops, reforestation, and retirement of critical areas to close-growing vegetation are adaptable to many conditions and usually are economically feasible and effective. To the engineer these measures are of value in protecting structures by retardation of flow and reduction of silt load.

Engineers find ready use for vegetation in a practical conservation program. Grasses, vines, and shrubs are used to protect cut-and-fill slopes on highways, gully banks, earth dams, and other erodible slopes. Grasses have been successfully used to stabilize the spillway sections of low dams serving small drainage areas, and diversion channels have been made practicable by filter strips of vegetation being placed immediately above them. Probably the most valuable use of vegetation in providing stable structures is as a lining for low-velocity channels. Terrace outlets and natural drainageways have been successfully protected against velocities of 8 to 10 feet per second by well established Bermuda grass sod, while grasses forming less dense sods have withstood velocities of 5 to 7 feet per second. Vegetation so used becomes a material of construction, and more knowledge is needed as to its value and dependability under unfavorable conditions. The agronomist supplies directions for the adaptation, propagation, and growth of such vegetation, but the engineer has contributed materially in determining the resistance of various grass covers, in improving methods of transplanting sods, and in reshaping and flattening cross sections so as to ensure more successful plant growth.

Severely eroded areas may be incapable of producing, unaided, a protecting cover of vegetation. The engineer may often use structural treatment such as terraces, contour ridges or diversions, to protect such areas while a cover is being established.

The third method—the interception and storage or diversion of surface water—is largely left to the engineer. An important feature of conservation engineering is that in the humid sections of the country the problem is largely one of getting rid of excess precipitation without damage to the soil by washing, while in the arid regions the problem is largely the reverse, that is, to hold on and in the soil as much as possible of the scant precipitation which occurs.

In the humid sections the interception and disposal of excess surface water is the engineer's chief job. Experiment station records indicate that erosion is directly proportional to the intensity and duration of flow. In order to shorten the surface run and prevent the cumulative increase in volume of flow down the slope, terraces or diversion ditches are constructed at intervals to act as primary interceptors. The intercepted water must be carried at nonerosive velocities into protected drainageways for delivery into natural streams or drainage courses. The terrace or diversion system should preferably be constructed on a farm-unit basis, but the initial planning for all run-off disposal measures should be on a watershed basis. Since farm boundary lines and watershed dimensions seldom correspond, it is often necessary to consider and provide for run-off from adjacent farms in the development of run-off disposal plans for individual farms. Farm run-off disposal facilities must be in harmony with the natural drainage requirements of the entire watershed.

In the semiarid regions the engineer is more concerned with storage and utilization of water. Dams for storage or for diversion and spreading systems, which divert concentrated flow to unwatered areas, are of primary consideration for both range and culti-

vated land. Level terraces on cultivated land, to impound run-off and distribute it over the surface for absorption and benefit to subsequent crops, are adaptable to the flatter slopes. Contour furrows and contour tillage provide numerous small depressions for surface storage and are adaptable to nearly all conditions.

In addition, there is often need to establish conservation practices on lands not used for cropping purposes and to build on them structures indirectly related to erosion control. For instance, the practice of controlled grazing on range land requires proper distribution and rotation of cattle over the area. Water is usually scarce in the range country, but water at strategic locations must be supplied to facilitate proper use of the range. The construction of impounding dams and stock tanks or well and spring developments to supply this water becomes a job for the engineer.

Where adequate erosion control cannot be economically provided on watersheds, it may be necessary to resort to desilting basins and silt traps formed by dams or dikes to arrest the flow of silt and protect irrigation or drainage systems from damage or to protect low-lying fertile lands from deposition of infertile material. Or it may be necessary to arrest the headward extension of an overfall-type gully, by dams or other structures, to prevent its encroachment on to highways or other improvements, or to stop its extension through fertile lands. Structures are sometimes required to stabilize the banks of a meandering stream and prevent the washing away of good farm land.

The improper application of irrigation water to steep slopes may be the cause of serious erosion. Adjustment of the methods of applying the water are sometimes necessary and may require a change in the irrigation system to afford either shorter runs over steep slopes or flatter grades in the delivery channels.

A special problem which involves practices already described but requires a somewhat different application is erosion control on highways. The highway location often cuts across the drainage pattern of a watershed and complicates the problem of safe run-off disposal. Considerable surface water may be intercepted by the road ditches, diverted from its natural channel of concentration and discharged at places where adequate protection is difficult to provide. Rearrangement of the highway drainage system, to permit more economical and effective disposal control, is sometimes possible. Gullies which form where side drainage enters over cut banks and at the entrance to culverts require correction by vegetation or structures or the diversion of the water. Erosion along the roadside itself may be causing damage to the road or adjoining lands. The job of protecting the cut-and-fill slopes and the highway ditches is based upon erosion-control principles already outlined.

So far this discussion has touched only on erosion-control and water-conservation methods. To those employed in conservation work it soon becomes apparent that the most effective conservation cannot be secured without proper land use. Slopes may be farmed that are too steep for cultivation and will probably require so many control measures that effective control cannot be secured at an economical cost. Some soils are extremely erodible and cannot be cultivated economically on moderate slopes because of the excessive cost of adequate control measures. A one-crop system may be followed where rotations are needed. Numerous other examples showing the need for proper land use could be cited. No combination of control measures is likely to achieve effective conservation if the land is improperly used.

Added responsibilities recently assigned by the Department of Agriculture broadens to some extent the horizon of the Soil Conservation Service. New activities consist of drainage, water facilities, irrigation, submarginal land acquisition and development, and upstream flood control. They promise to make possible the more complete attainment of the objectives of the Service. They provide additional methods of treatment to achieve proper land use. As the Service will be benefited by these activities, so also will the activities themselves be benefited by increased scope and by integration with other activities to secure a fully coordinated conservation program. For instance, an action program for flood control may embrace application on a watershed basis of most of the conservation features already developed. Soil improvement practices will be required to decrease run-

(Continued on next page)

This issue of SOIL CONSERVATION was planned too early to include engineering articles on drainage, irrigation, and the development of marginal land. It is expected that later issues of the magazine will contain articles in which a correlation of these practices with soil-conservation objectives will be discussed. The development of more complete soil-conservation and land-use programs has been made possible by recent changes in the Soil Conservation Service.

FARM DRAINAGEWAYS AND OUTLETS[1]

By C. L. Hamilton[2]

PROPER disposal of surface run-off is a major problem in the development of satisfactory farm conservation plans. It is poor planning to expend funds and effort in securing proper land use with contour cultivation, conservation rotations, strip cropping or terraces to conserve the soil on sloping fields, and at the same time to neglect the drainageways which convey concentrated run-off. Ultimate gullying in neglected drainageways will eventually undermine and destroy the soil conservation measures on the adjacent slopes as well as any benefits derived from them. Supporting field examples can be pointed out everywhere. In the South, where terracing with contour tillage has been widely used for many years, inadequate outlets frequently lead to destruction of the terraces and accelerated gullying often to such extent that abandonment of entire fields became necessary. In other sections gullying branching out from unprotected drainageways has destroyed many fields where rotations, contour cultivation, and strip cropping were practiced.

The location of drainageways and outlets also has a marked effect on the ultimate success of the entire farm conservation plan. Recent field observations

[1] The term "drainageways" refers primarily to channels of surface drainage in the upper reaches of watersheds or in unit drainage basins. "Outlet" is a more restricted term and refers only to drainageways that are provided to receive and convey the discharge from the ends of terraces.

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CHAMBERS *(Continued from preceding page)*

off; water flow retardation by vegetation and structures will be necessary; the reestablishment of vegetal cover over critically eroding areas will be essential as a method of silt control; channel improvement and protection, highway erosion control, and gully control over the watershed, all will enter into the picture. In addition to regular erosion-control work, the engineer must be alert to the establishment of upstream detention basins for the slow and orderly passage of peak flows. All the practices used must, of course, be economically feasible from a flood-control standpoint, and benefits accruing must be in excess of the cost.

It will be necessary to evaluate each practice from the standpoint of water flow retardation and silt reduction. A great deal of study will be necessary for such determination. Of particular interest to the engineer will be the routing of peak flows through the tributaries. If upstream detention structures are feasible and practical, there is still the problem of synchronizing the delivery of tributaries so that peak flow at danger points will not be increased. The flood crests in the numerous tributaries may present a complex problem when it is considered that flood damage to a greater or less degree may occur on any of them, and that the same water may participate in more than one overflow in its passage down the watershed. The relative degree of flood damage that may occur in the successively larger tributaries may be a primary consideration in determining the value of upstream storage.

The need is acute for data from small areas relative to run-off characteristics from various types of watersheds, and the engineer will be considerably handicapped until more accurate information is available. Devising means to acquire this information becomes one of his more immediate responsibilities.

Land drainage is an engineering activity of long standing, and proper drainage is often necessary for best land use. Fertile bottomlands, too wet for agriculture, can often be placed in profitable cultivation by drainage, thus permitting the retirement of eroding slopes at other places on the watershed. Under certain conditions, the removal of excess ground water by underdrains will prove valuable in increasing the rate and amount of absorption from rainfall.

The Water Facilities Act provides for the storage and use of surface waters and the development and use of subsurface waters in the arid and semiarid sections of the country. The act is of great significance to conservation engineers in these areas since it enables them to consider the watershed as a unit and plan for complete and judicious use of all the water available. The adjustment of supply to needs, where the supply is not sufficient to meet all requirements, must be handled cautiously and in accordance with local laws and water rights, but, in addition, the conservation engineer is concerned with supplying needs that will promote the proper use of land. Coordination with other conservation features is necessary to ensure proper land utilization and protection to the structures involved.

directed attention to farms where complete soil conservation practices had been installed but the entire plan failed to secure wholehearted support of the farmer because of improper drainageway locations. Once established, the relocation of drainageways is usually a costly and discouraging undertaking. Proper drainageway locations are largely dependent upon the natural drainage pattern of the area involved. Drainageways located according to property lines, or for the primary purpose of facilitating conservation measures previously installed, often lead to costly or inconvenient farming systems.

The necessity of establishing satisfactory run-off disposal plans at the outset was not generally recognized during the first attempts to develop complete soil conservation plans for individual farms. The earlier efforts were concentrated on problems of proper land use and determination of practical types of practices to check soil losses on individual fields. It was not until many of the resulting farm plans had been established that the importance of over-all run-off disposal plans were fully realized. The installation of many of the plans proved to be uneconomical, while others required costly readjustments before satisfactory results could be obtained. The most disappointing experience resulted from improper location of many of the initial drainageways; their relocation, to facilitate the establishment of subsequent conservation measures on adjacent fields or farms, required extensive readjustments and expense. Even today some engineers and conservationists do not fully appreciate the necessity of developing adequate run-off disposal plans at the outset.

Planning Run-off Disposal Systems

There are two distinct phases in planning farm run-off disposal systems. The initial or general planning involves the selection of the number, type, and location of required drainageways, and of the installation procedure for each. The secondary or detailed planning involves the determination of capacity, design, and construction or establishment details. The former phase should be included in the development of initial farm conservation plans and the following discussion will be limited to this aspect of run-off disposal planning.

The first step in planning a farm run-off disposal system is to make a physical inspection of the farm and the adjacent areas. The main drainage features such as draws, ridges, and slopes should be noted. Their location and condition are of particular importance. Field and property lines, roads, buildings, fences, etc., while of lesser importance, should also be noted. This preliminary inspection will reveal the general drainage characteristics of the area and enable a tentative selection of at least the main depressions that should be reserved for permanent drainageways. The number of lateral drainageways required will depend not only on the topographical features but also on the soil conservation practices to be used. For example, where run-off interception is to be provided by the use of terraces or diversion ditches, the retention of some of the minor depressions as permanent drainageways can often be avoided. On areas where no run-off diversion measures are used, all lateral depressions that carry any applicable amount of run-off must be reserved as drainageways. As land use and soil conservation plans are developed for the area, the field boundaries, fence lines, and meadow or pasture areas can often be adjusted so as to make it easier to establish and maintain the selected drainageways.

On areas to be terraced the problem of locating and establishing outlets is inseparably associated with planning the terrace system. The cost of terrace construction, and the ultimate success of the terraces, are dependent upon proper planning of outlets. Conversely, adjustments in the location and in the direction of the flow of terraces will often greatly facilitate outlet control. For example, changing the direction of the terrace grade near the center of a terrace, or running the grade of alternate terraces in opposite directions, will diminish the concentration of run-off and often make it possible to distribute the run-off from a terraced field over native cover on adjoining areas. Where special outlet strips or channels are required, it is often more satisfactory to drain terraces toward the outlet channels from both sides so that each outlet channel will serve a larger area, thus reducing the number required.

It has been found necessary to plan surface drainage systems according to natural drainage units. A drainage unit comprises a natural depression or drainageway together with the land that drains toward it. This means that the initial surface drainage plans for all fields or farms within the drainage unit should be developed concurrently, irrespective of boundary lines. Plans should provide for continuous conveyance of the run-off and economical development of the drainageway from field to field and from farm to farm until a stabilized watercourse is reached. With a properly planned procedure that is in harmony with the natural drainage pattern, drainageways can usually be systematically established, if necessary, by field or farm increments so that each part can be fitted together without difficulty or expense when the final conser-

vation job is completed for the entire drainage unit. In some areas the most effective field application of this plan may even involve the cooperative development and maintenance of certain drainageways by two or more land owners. Recent experience has shown that cooperation between landowners and highway officials, in the subsequent development of dual-purpose drainageways that carry run-off from the highway right-of-way as well as from the adjacent farm land is often advantageous.

various climatic, geographic, soil, and type-of-farming regions.

Due to the diversity of conditions encountered, it is obviously impossible to select a standard method of drainageway protection and attempt to apply it universally. The only satisfactory procedure is to determine in what order the various types of drainageways should be considered and what form of each type is best adapted locally and can be economically established and maintained. From the standpoints of economy and practicability, including ease of establishment, the various types of drainageways should be considered in the following order:

1. Vegetated individual outlets (terraced areas only).
2. Meadow or pasture strips.
3. Vegetated channels.
4. Mechanical protection.

In field practice the natural conditions encountered will often prohibit the use of certain types, but the types should usually be given consideration in the order named and no method should be discarded as impractical until thorough investigation has proved it to be so.

Classification of drainageways and outlets

Drainageways	Natural		Constructed		
	Vegetated	Unvegetated	Vegetated	Mechanical	Miscellaneous
Draws (unterraced areas)	Grassed [1] Wooded	Rock	Meadow strip Pasture strip	Drop check Lined [2]	Combination. Unlined.
Individual terrace outlet	Grassed slope [1] Wooded slope	Rock slope	Grassed slope [1] Wooded slope	Drop check Lined [2]	Absorptive. Accumulative.
Collective terrace outlet	Grassed [1] Wooded	Rock	Meadow or pasture strip. Field or roadside channel.	Drop check Lined [2]	Combination Unlined.

[1] Often referred to as meadow or pasture depending upon how the forage is utilized.
[2] Discharge velocities are usually higher in lined channels and the channels are sometimes referred to as high velocity.

Selection of Type

Natural drainageways that are still protected by native vegetation should always be given first consideration. They should be protected and utilized to the fullest extent possible because it is usually difficult to reestablish or duplicate these original drainageways and, at best, it is frequently a costly procedure. Natural drainageways that have been only partially damaged by overgrazing, or by the development of a few breaks in the original cover, can usually be repaired or restored. The sooner this is done the more successful it will be and the smaller will be the expenditure of labor and materials required.

Since much of the native covering has been plowed up or destroyed and so many drainageways have been severely damaged by gullying, it is necessary to establish many new ones or rebuild old ones. In the reestablishment of these drainageways the results are usually most satisfactory where the natural features are reproduced as nearly as possible. There are some areas, however, where the soil and climatic conditions or artificial conditions introduced with agricultural practices may justify or even necessitate some modification of nature's procedure. It must be recognized that problems of drainageway development are neither equal in importance nor uniform in character in the

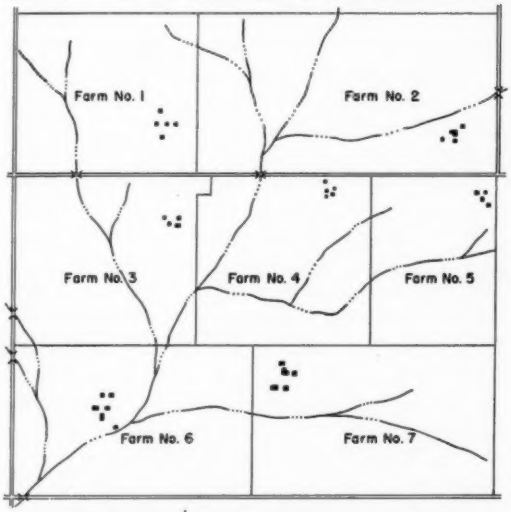
Pretreatment of Drainageways and Outlets

In most areas it has been found not only hazardous but also expensive to attempt to establish grassed drainageways or outlets at the same time that they are being used for the disposal of run-off. This is particularly true on areas where terraces concentrate additional run-off in the drainageways. Newly prepared seedbeds, seeds, fertilizers, and young plants offer little resistance to erosion and are frequently washed out unless special precautions are followed. Solid or strip sodding, when properly anchored, will sometimes carry run-off without harmful results immediately after it has been placed. This, however, is a relatively

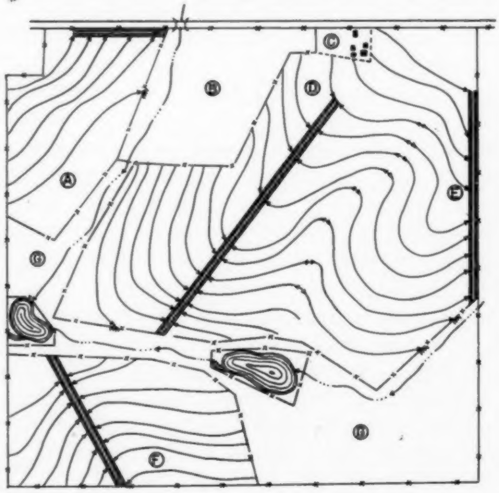
costly method of establishing vegetated drainageways, and the expense retards extensive use of vegetal protection. It is sometimes even difficult to anchor newly placed sod in certain channels in such a way that it will not be damaged by heavy run-off. Damage from run-off is more acute in the establishment of vegetation in outlet channels than in wide grassed drainageways because of the higher velocities produced in the smaller channels. There are several possible methods that can be used to save expense, eliminate the run-off hazards, and make the development of seeded drainageways more dependable and practical.

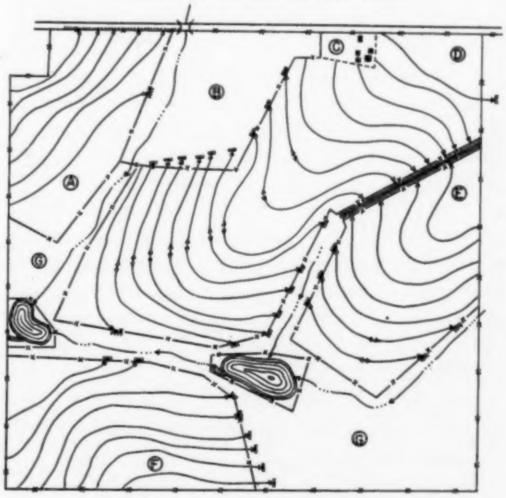
On areas to be terraced one of the most promising plans is the establishment of outlets before the terraces are constructed. A few years ago a general feeling prevailed that the application of this practice would prove impractical under field conditions. Recent observations and field tests, however, have shown that the establishment of outlets in advance of terracing can, with proper planning, not only be practical but distinctly advantageous in many areas and that it should be given first consideration in the development of any extensive terracing program. As a result of this practice, some Soil Conservation Service project engineers report that C. C. C. camps have been able to accomplish approximately five times as much outlet work as otherwise. They have also been able to establish economical outlet protection where other methods have proved too costly, and the greater accomplishments have resulted in extending the work to many more farms. This experience led to the adoption of the plan as a standard procedure in all field work in Region 2. Establishment of outlets in advance of terracing has also been tried out in Region 4 and is now being extensively advocated in all field work within that region.

The success of this method has been made possible by the complete farm run-off disposal plans which include the number, location, type, and order of drainageway development as a definite part of preliminary farm



Satisfactory run-off disposal on individual farms is dependent upon the development of economical drainageways that are in harmony with the natural drainage pattern of the unit watershed involved. The upper illustration to the left shows why it is usually necessary to consider several fields or farms in the development of initial run-off disposal plans. The lower illustrations show (left) incorrect and (right) correct detailed run-off disposal plans for farm No. 4. Fields A, D, E, and F are terraced and cultivated. B is in woods and G is in pasture. While the incorrect plan may provide safe run-off disposal, its establishment and maintenance will require at least twice as much work and expense as would be necessary with the correct plan.





conservation planning. The location of all terraces to be used, and their direction of drainage, are also specified in the run-off disposal plans. Where this practice is not followed, it is difficult effectively to establish outlets in advance of terrace construction. It is important that the outlets be located and constructed so as to facilitate later terrace construction. Otherwise, they cannot be efficiently used when the final conservation measures are installed and they will represent wasted efforts and expenditures.

For the most effective use of pre-established outlets, the order of terrace construction is largely determined by the order in which established outlets can be made available. Terrace construction is arranged so that the areas for which natural outlets are available, or for which outlet channels require solid sodding or mechanical protection, can be terraced the first year while the vegetation is becoming established in other outlets. Outlets must be established as early as possible in order that the final terrace construction work will not be delayed. The change from the common practice of treating outlets following terracing to the new practice of establishing outlets in advance of terracing will involve a transition period in any terracing program. During this period it may be advisable to establish part of the outlets after terracing so that the terrace construction work may be continued without undue interruption. The length of the transition period will largely depend upon the additional effort directed to outlet construction or the rate at which outlet construction can be temporarily accelerated. The normal rate of outlet construction can be resumed once the outlets are well in advance of terrace construction. The shorter the transition period can be made, the sooner the full benefits of pre-established outlets can be achieved.

Where grassed drainageways are to be established by seeding on unterraced areas or on terraced areas where established outlets are not available, the use of some form of temporary run-off protection is often advantageous. Even with pre-establishment of outlets on areas to be terraced it is often necessary to provide some additional run-off protection during the period in which the grasses are becoming established. In the South where Bermuda grass is commonly used for drainageway protection, the problem seems to be somewhat less acute. Here the Bermuda grass is usually established from rootstalks and stolons by spot, spring, or broadcast sodding. During the initial stages, however, even this procedure is often benefited by some form of temporary run-off protection.

The practice of diverting the run-off, by means of temporary dikes or ditches, until the vegetation becomes established in the permanent drainageway is often used. The use of a quick-growing annual crop, to stabilize the drainageway before seeding the grasses, is sometimes advisable. Small grains or Sudan grass, domestic ryegrass and similar crops may be seeded in the spring to hold the soil effectively and produce a residue in which to seed the grasses the following fall. Nurse crops may also be seeded with the grasses to afford quick protection, but care must be exercised not to seed too lavishly. Where practical, such run-off retention measures as contour ridging, furrowing, listing, and subsoiling on the contributing watershed, may sufficiently reduce the run-off temporarily to assure satisfactory establishment of drainageway vegetation. On some areas where pre-established outlets were not available, it has been found that subsoiling only the terrace channels and outlets, to a depth of about 18 inches, reduced the run-off sufficiently during the following year to permit the establishment of satisfactory vegetal protection in the outlets.

Providing new grass seedings with some form of surface protection has also facilitated the establishment of drainageway vegetation in some sections. Surface mulching not only protects newly prepared seedbeds, seed, and small plants from run-off and hard rains, but it conserves moisture and produces a surface condition that encourages the germination and growth of small grass seeds. The mulch can be produced by properly anchoring a thin but continuous layer of straw, corn fodder, old hay, or fine brush over the entire seeded area. Loosely woven burlap, tightly drawn and staked to hold it in place, provides good surface protection. While this treatment is more expensive, it may frequently be used advantageously on small areas or at vulnerable points in larger areas. Regardless of which method of run-off protection is used, it is essential that adequate seedbed tilth and fertilization be provided, and that suitable seeding rates and mixtures be used for satisfactory results. Even with run-off protection, it cannot be expected that grasses and legumes will thrive well where topsoil and necessary fertility are lacking.

Since the organization of the Soil Conservation Service, cooperative agreements have been signed for 64,711 farms or ranches, comprising 32,668,979 acres for complete soil- and water-conservation practices. On this acreage 87,626 miles of terraces protecting 1,268,544 acres have been constructed, and 3,418,387 soil-conservation dams have been installed.

GRAPHIC SOLUTION OF CHANNEL DIMENSIONS BY THE MANNING FORMULA

By H. G Jepson [1]

THE determination of flow of water in open channels presents a rather complicated problem because of the variety in shapes and sizes of cross sections, the great variation in roughness of channel surfaces, and the apparent discrepancies in experimental data. Many formulas, some of them based on rather meager experimental information, have been developed. Of these the Manning formula is being used extensively by agricultural engineers to compute flow of water in open channels. This formula lends itself readily to solution of diagrams or tables and is more simple of form for analytic solution than most other formulas that have been used. It also appears to be quite accurate within the range of ordinary computations encountered. It is for these reasons that it has been selected for solution of channel problems.

The Manning formula as usually written is:

$$V=\frac{1.486}{n}\ R^{\frac{2}{3}}S^{\frac{1}{2}}$$

But for solving various types of problems it is more convenient to express it in terms of the discharge equation:

$$Q=\frac{1.486}{n}\ AR^{\frac{2}{3}}S^{\frac{1}{2}}$$

where Q = discharge capacity of channel in cubic feet per second,

n = coefficient of roughness for various channel conditions,

A = cross-sectional area of flow in square feet (sometimes expressed in terms of b and d where b equals bottom width of channel and d equals water depth),

R = hydraulic radius of the channel in feet or the cross-sectional area divided by the wetted perimeter,

S = slope, or fall per foot

and V = mean velocity of water in feet per second.

When it is considered that small changes in the channel cross section, in the slope, or in the roughness coefficient may materially change the discharge capacity of that channel, it is readily apparent that a graphical solution of problems would be highly desirable. By ordinary mathematical solution it is necessary previously to select approximate channel dimensions and then substitute them in the formula to determine whether the assumptions meet the conditions of the problem. A good graph usually enables direct selection of the proper dimensions without resorting to tedious cut-and-try methods and, in addition, gives a much better picture of the practical limitations of the various factors entering into the design. Graphs also enable the selection of a greater number of conditions and combinations than is possible by the use of tables or is ordinarily attempted analytically.

A very compact and relatively simple chart for solution of outlet channel dimensions has recently been developed by V. W. Thalmann, associate agricultural engineer, Soil Conservation Service. The chart is reproduced on page 163. It is to be used only for trapezoidal cross sections having 4:1 side slopes and is best adapted to the design of vegetated outlet channels. Similar charts can, of course, be made for any side slopes desired. The chart enables ready determination of channel dimensions within the range of values ordinarily encountered. The various factors graphically obtainable are V, n, R, S, A, b, d, and $\frac{b}{d}$ ratios including the most economical cross section if desired. It should be noted that the velocity values V are based on a value n of 0.0372 which represents a fairly average figure for accepted values of n for grassed channels in reasonable condition.

If it is desired to apply other values of n a different method of reading velocities is required. A sample problem involving two different values of n is being included in order to facilitate use of the chart. In one case n will be the base value of 0.0372 and in the other will be 0.035. The dotted key solution on the chart is based on the value n of 0.035 in order to illustrate the method of reading velocities when other than the base value 0.0372 is used.

Sample Problem

Given: A terrace outlet channel is to be constructed down a 7-percent slope and treated with vegetation capable of withstanding a maximum velocity of 5½ feet per second. The expected maximum run-off flow to be provided for is 44 cubic feet per second.

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Find: Using 4:1 side slopes and a trapezoidal cross section, what bottom width of channel is required and what will be the depth of flow at capacity discharge?

Solution 1 (When $n=0.035$): (See dotted lines in key solution on chart.) With an n value other than 0.0372 the velocity values cannot be read direct. It has been found, however, that certain relationships exist whereby velocity values may be laid off along the slope lines S when the slope is expressed in percent. Thus, for any values of n other than 0.0372, velocity must be read along the slope scale.

Continuing with the problem, follow the velocity ($5\frac{1}{2}$) along the $S=5\frac{1}{2}$ line to its intersection with $n=0.035$. From this intersection point descend vertically to the intersection with $S=7$. From here read horizontally to the intersection with the required A which is $\frac{Q}{V}=\frac{44}{5.5}$ or 8 square feet. This point falls at approximately 0.36 for d and 20.2 for b. A channel with a bottom width of 20.5 feet and a depth of 5 inches should be used for the conditions given. In field practice additional depth is usually provided to give the necessary factor of safety.

Solution 2 (When $n=0.0372$): (Since the base value of 0.0372 is assumed for n, the velocity values given on the chart may be read direct and the other n values ignored.) Therefore, follow the vertical line $V=5\frac{1}{2}$ to its intersection with the required S line (7). From this point, read horizontally to the intersection with the required A value which is 8 square feet. This intersection point is found to fall at about 18.2 on the b scale and about 0.40 on the d scale. Thus, a trapezoidal channel with a bottom width of 18.5 feet and a depth of about 5 or 6 inches should be used for the conditions given. It will be noted that the value of R can also be obtained during the operation if it is desired to get a reading of the hydraulic radius.

It is evident that such a chart is a great time-saver over laborious substitutions in a formula, and is sufficiently accurate for the design of vegetated outlets where dimensions ordinarily need not be computed to an accuracy of more than a few inches. The fact that individual charts can be used only for channels with side slopes equal to those on which a chart is based, does not materially affect their usefulness because usually certain side slopes are decided upon in a given locality for which charts can then be compiled.

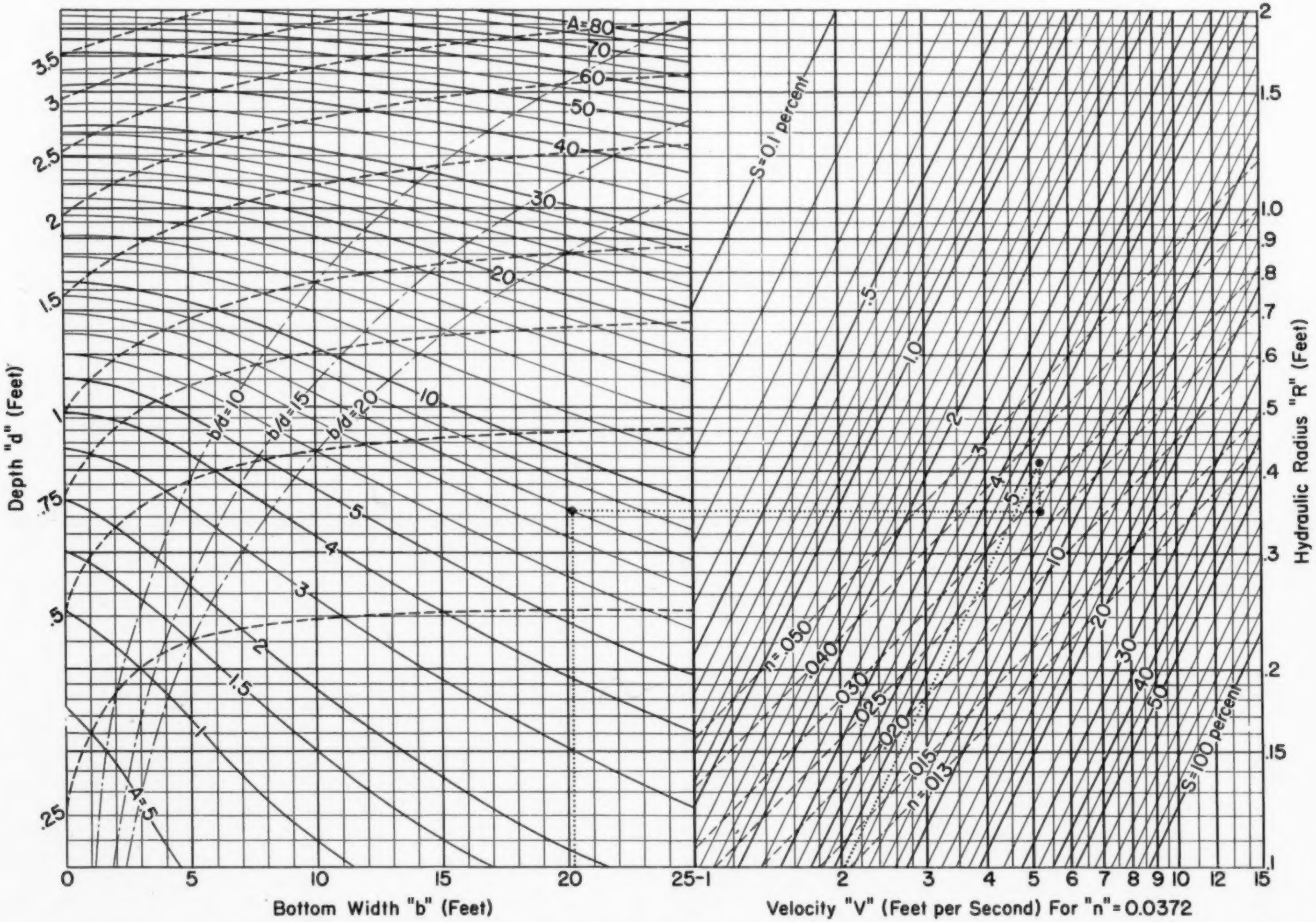
As has been previously pointed out, the Thalmann chart is best suited for design of vegetated outlet channels. Where it becomes necessary to resort to masonry or concrete lining for outlet channels, additional factors should be considered in design. For example, in vegetated outlets relatively wide, shallow cross sections are used in order to increase surface contact with water and thus keep velocities low. Where masonry or concrete linings are used, more economical cross sections should be provided. It is evident that if an open channel has a fixed cross-sectional area and slope the maximum discharge will result when the area is so shaped and proportioned that the surface contact between water and channel lining is kept to the minimum. Under such a condition frictional resistance will be a minimum and maximum velocity will occur.

It is a well-known principle that of all geometric figures the circle encloses the greatest area per unit of perimeter. Similarly, then, for open channels the half-circle cross section would present the least amount of surfacing. There are, however, other factors to consider, such as ease of construction which frequently makes the half circle unsatisfactory for general field use. From the standpoint of practical construction, the trapezoidal and rectangular sections are generally the most popular for open channel use. Of these two, the trapezoid, when constructed with the sides and bottom of equal length (half hexagon), more nearly approaches the shape of a half circle and thus should receive consideration where it is necessary to construct a high-velocity channel that must be lined with relatively expensive materials.

A chart [Graphic Solution of Concrete Channel Dimensions (Most Economical Trapezoidal Cross Section)] has been prepared to provide a diagrammatic solution for the hydraulic elements of a trapezoidal channel having the most effective cross section. This chart is shown on page 164. The chart is based on the Manning formula, and the various terms used have the same meaning as previously described for the Thalmann chart. A value n of 0.014 was used, as this is commonly recommended for concrete-lined channels in good condition. In case other lining is used, a different n would be necessary. For example, a good cement-rubble surface would require an n of about 0.020.

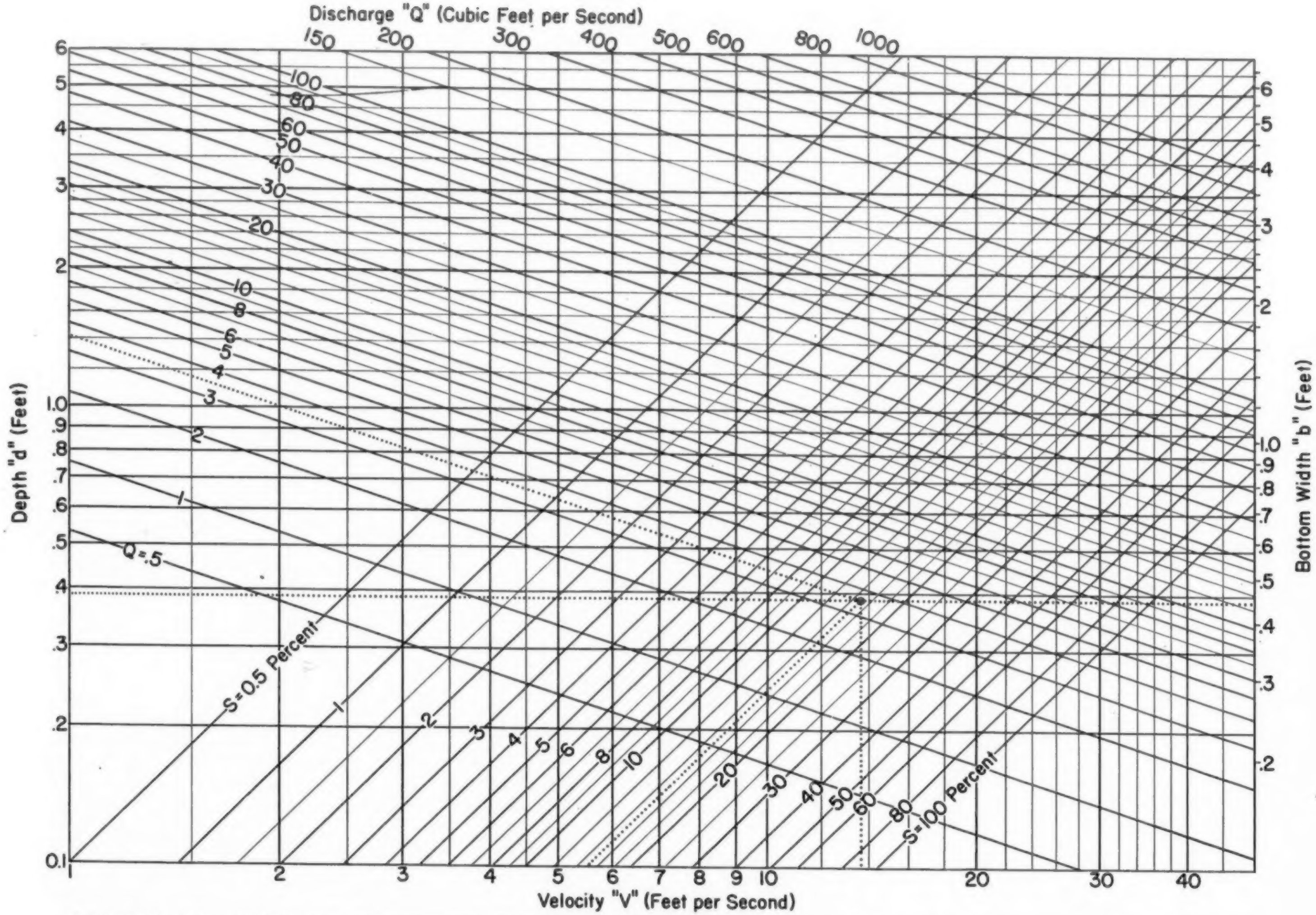
The chart for concrete-lined channels can be used in the design of channels lined with cement-rubble if the design values of Q are first divided by the factor $\frac{0.014}{0.020}=0.70$. In other words, to discharge an equal quantity of water within a given period of time a somewhat larger cross section is required for rubble masonry than for concrete. This results because of differences in frictional resistance. A sample problem is being included to indicate usage of the chart. Solution 1 is for a concrete-lined channel, and solution 2 is for rubble-masonry lining.

(Continued on p. 165)



GRAPHIC SOLUTION OF OUTLET CHANNEL DIMENSIONS. (Trapezoidal Cross Section with 4:1 Side Slopes)

By Manning Formula $V = \frac{1.486}{n} R^{2/3} S^{1/2}$



GRAPHIC SOLUTION OF CONCRETE CHANNEL DIMENSIONS. (Most Economical Trapezoidal Cross Section)

By Manning Formula $V = \frac{1.486}{n} R^{2/3} S^{1/2}$: For n = 0.014

JEPSON *(Continued from p. 162)*

Sample Problem

Given: A high-velocity channel of trapezoidal section is to be constructed down a 15-percent slope. The expected maximum run-off flow is 3.5 cubic feet per second.

Find: What bottom width of channel is required and what will be the depth of flow at capacity discharge? Also, determine the velocity at peak discharge.

Solution 1: (See dotted lines in key solution on chart.) Follow the $Q=3.5$ line to its intersection with $S=15$. From here read horizontally to the left for d values, horizontally to the right for b, and vertically down for V. It will be found that d is approximately 0.38 feet, b about 0.44 feet, and V about 13.6 feet per second. Thus, a trapezoidal channel about 5 inches deep and 5½ inches wide at the bottom should be able to carry the peak discharge. Since the section is a half-hexagon the channel sides should be of the same length as the bottom. This will give side slopes of 0.577 to 1, or approximately 0.6 to 1.

Solution 2: (Rubble-masonry lining) Divide $Q=3.5$ by 0.70 which is 5.0. Follow the $Q=5$ line to its intersection with $S=15$. From here the values of d and b can be read as was done in solution 1. It will be found that a trapezoidal channel about 5½ inches deep and about 6¼ inches wide at the bottom is required to carry 3.5 cubic feet per second discharge when rubble-masonry is used for lining. The channel sides will, of course, have the same slopes as in solution 1. Their length should be equal to the bottom width or 6¼ inches. The velocity will be 0.70 of the velocity actually read on the chart, or 0.70 (14.9) = 10.5 feet per second.

It will be noted that the chart provides for velocities V up to 50 feet per second. However, velocities above 25 feet per second are extremely difficult to control and ordinarily will require careful design for conveyance structures if satisfactory results are to be expected. High velocities generally require the use of velocity dissipators at the outlet end of the channel. Another factor that may affect design under conditions of high velocity is entrainment of air in the water. Water flowing swiftly down a long flume does not follow invariably the continuity equation $Q=AV$ for any value of A assumed. Air entrainment may expand the water to such an extent that the computed cross sections will be inadequate to carry the design discharge. It is for these reasons that the higher velocities shown in the chart should be used with caution and not indiscriminately applied to any and all conditions encountered in the field.

Attention is also called to an item which is sometimes neglected in design, namely, that in high-velocity channels the slope is often far in excess of that required to discharge the water at its initial or entrance velocity. This will cause the water to accelerate until uniform flow exists. The chart is based on a condition of uniform flow and mean velocity for the various slopes shown. In design, therefore, it will be necessary to investigate and allow for entrance losses in order that the full design capacity of the channel will be utilized.

MAINTENANCE OF THE DRAINAGE-TYPE TERRACE

By A. Carnes [1]

IF terraces are to pay dividends, a systematic maintenance program must be provided and carried out on every farm on which they are used. The construction of even a well-designed system of terraces does not in itself assure complete erosion control. Construction is only the initial stage, and the success of terraces in erosion control depends on whether they are properly maintained and farmed after construction. Too often erosion-control efforts cease after terrace construction, and consequently, the expenditures involved are wasted. This is true of both the old terracing areas in the South and the newer ones in the Central and Northern States. Even in some of the earlier soil conservation demonstration projects the importance of terrace maintenance was overlooked and not adequately provided for in the development of the initial field programs.

The rapid rate of decline in the capacity of terraces—and the capacity is a direct measure of their value—is well illustrated by the following example: A field of approximately 45 acres was terraced on a cooperator's farm in one of the Soil Conservation Service demonstration project areas in the winter of 1934. When completed, these terraces were carefully checked and

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Close-growing vegetation filters silt from the run-off, which concentrates in this depression between terraces and protects the channel from dangerous deltafication.

found to be up to specifications in every respect, with ample channel capacity to take care of the expected volume of run-off. During the following year improper tillage and maintenance practices were followed. The project manager, noticing the results, had the terraces rechecked very carefully early in the spring of 1936. The results were astounding. Instead of having ample channel capacity as originally constructed, many sections were found in the terraces where the capacity had been reduced by more than 50 percent. This meant that with the next heavy rain the terraces would overtop and thereby aggravate rather than alleviate erosion.

The good effects of proper maintenance are just as striking as the ill effects of improper maintenance. Terraces have been observed that were even slightly undersize immediately after construction, but with proper maintenance they were soon brought up to adequate size and this section was easily maintained year after year. Some examples have been observed where the capacity of terraces was actually increased year after year due to the maintenance practices followed until the terraces became entirely too large. Results at the soil and water conservation experiment stations have also shown that this is possible by a certain manipulation of regular cropping and tillage operations.

In the development of farm or district erosion-control programs, terrace maintenance must be given due consideration and provisions made to facilitate its establishment as a regular farm operation at the outset. Where soil conservation demonstration projects failed to provide for terrace maintenance work in the development of their initial field plans the results were discouraging. The farmers who were not impressed with the need for terrace maintenance or shown how it could be accomplished as a regular part of their tillage operations, failed to appreciate its necessity and their terraces deteriorated rapidly. By the time the seriousness of the condition was recognized and supplemental maintenance methods developed, demonstrated and adopted by the farmers, terraced fields suffered seriously and many required rebuilding.

In other project areas, extra large terraces were purposely constructed to offset the expected lag in terrace maintenance work. This procedure was particularly tempting in areas where terracing was a new practice. It usually doubled or tripled terrace construction costs and in the end failed to secure adequate maintenance. This policy is still being followed in some areas and as yet its shortcomings have not been fully realized. To the more alert observers the fallacy of devoting excessive funds to construction in order to compensate for inadequate maintenance programs is clearly evident. The only logical procedure is to include terrace maintenance as a definite part of the original conservation plans and provide necessary facilities for its development, demonstration, and adoption, so that maintenance will be appreciated and practiced from the outset.

Terrace maintenance may be divided into two component parts: (1) The use of proper conservation practices, particularly contour tillage and close-growing vegetation, to check erosion and retain the silt on the terrace interval, thereby preventing deposition in the terrace channel below; (2) the use and manipulation of tillage equipment which produces lateral soil move-

The value of this terrace has been largely destroyed by excessive silt deposition in the terrace channel.

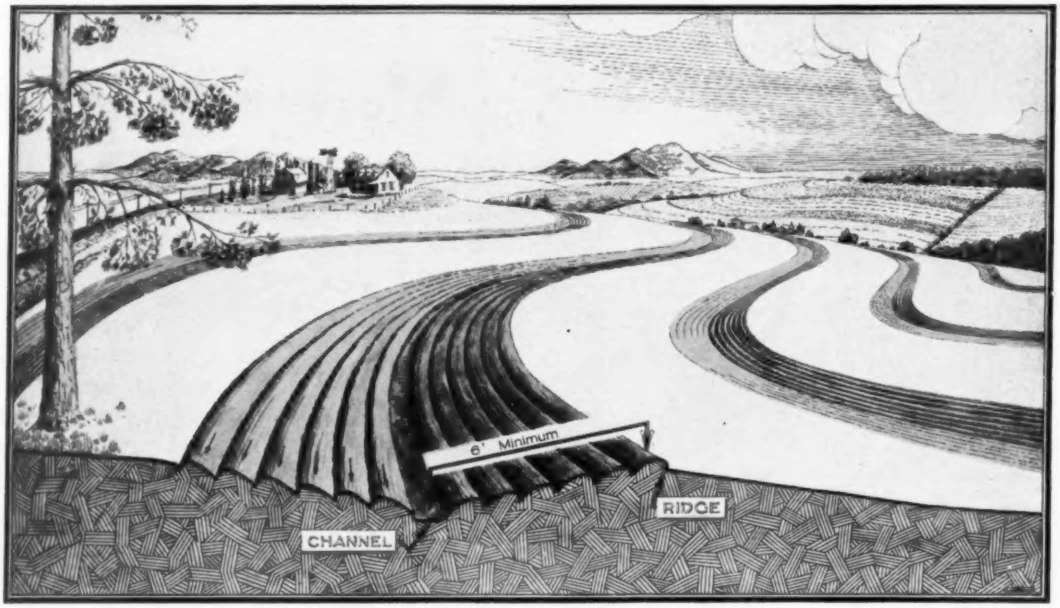
ment, such as plows, disks, etc., so that soil deposited in the terrace channel can be worked out at regular intervals.

The ideal objective is to develop the first part to such a degree that soil movement is checked or the soil filtered out before the run-off reaches the terrace channel. This is not always practical under some field conditions. Even contour operation of most tillage equipment over a terraced field has a tendency gradually to reduce the size of terraces, so that it is usually necessary to rely upon the second part to provide necessary supplemental maintenance. Where good farm conservation practices are followed, sufficient supplemental maintenance can generally be provided by proper manipulation of regular plowing operations. Where erosion inducing practices are followed, additional supplemental maintenance in the form of grader or scraper work is usually necessary and, in most instances, adequate maintenance becomes impractical.

Contour cultivation and the use of close-growing vegetation are two of the most effective conservation practices that aid terrace maintenance. These are now commonly accepted as standard erosion-control practices, and they need little additional elaboration. It has been shown that an arrangement of close-growing strips of vegetation, on the terrace interval and immediately above the terrace, will aid a great deal in preventing silt from entering the channels. Strip cropping can usually be molded into the regular farming operations and crop requirements. Where diversion ditches, or diversion-type terraces with wide spacing, are used it is essential that a sufficiently wide permanent strip of close-growing vegetation be maintained immediately above the channel to protect it from excessive silting. The entire terrace interval on badly eroded areas or critical slopes should be planted to close-growing crops.

Throughout the cotton and tobacco belt of the Southeast, small depressions commonly occur in the terrace interval. Some are natural while others are the result of erosion. Accumulation of run-off in these depressions often leads to dangerous deltafication in the terrace channel where the concentrated run-off is discharged from the depression. Observations on several projects in this area indicate the advisability of seeding these depressions to close-growing vegetation so that the silt is filtered out before it reaches the terrace channel. This practice has decreased the number of terrace failures and the amount of hand and plowing maintenance required during the cultivation season. In the Southeastern States, proper row arrangement with reference to the terrace channels has also facilitated terrace maintenance. A row is placed on each side of the channel leaving a 4- or 5-foot middle so that the flow line will be left open during the cultivation season. At the last cultivation, when necessary this wide middle may be plowed out with a moldboard plow to provide for heavy rains in late summer.

The carrying capacity as well as the shape of the terrace can be improved by proper plowing methods. Considerable ingenuity must be exercised by the plowman in the manipulation of the plow and the location of deadfurrows and backfurrows so that the channels are maintained and terrace cross sections improved. This may be done by either the one-land or



One-land method of terrace maintenance.

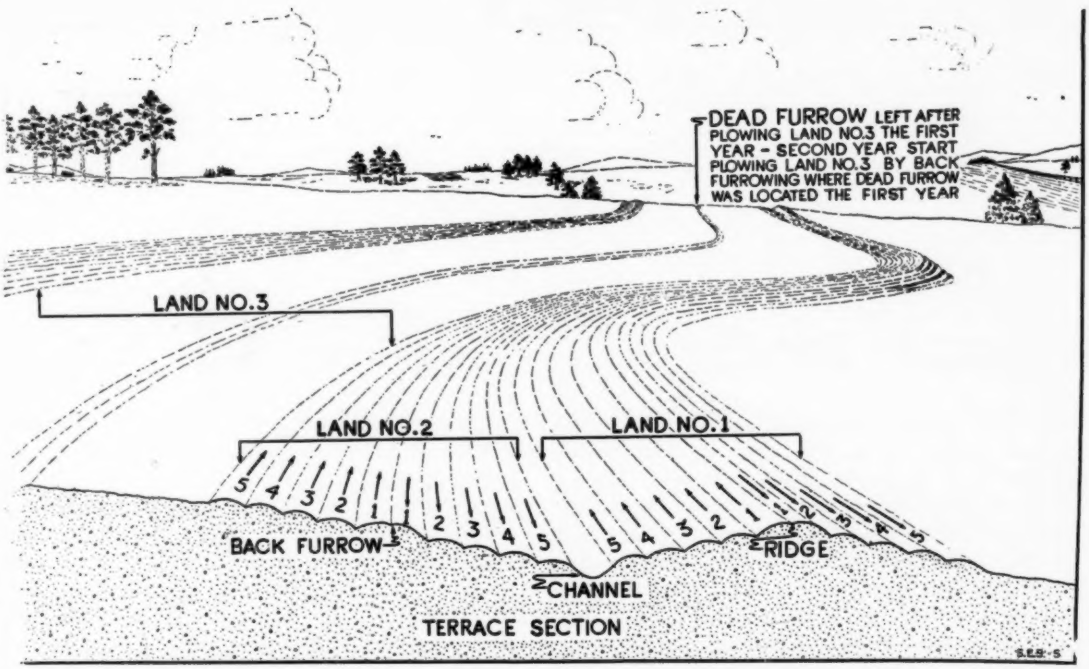
the two-land method, as illustrated in the accompanying charts. Minor variations may be necessary in some areas to meet local conditions. When land is prepared by flat breaking or complete plowing, the two-land method is admirably adapted, and maintenance becomes a part of land preparation. In areas where flat breaking is an annual practice and erosion is not severe, this procedure will usually provide adequate maintenance. When more severe silting has occurred in the terrace channel, two plowings may be necessary to obtain sufficient cross-sectional area to accomodate the expected run-off.

The one-land method has been developed and adapted by the Soil Conservation Service in the Southeastern States because of certain local conditions, but it may be adapted to other areas where similar conditions prevail. It has proved most practical where the rotation and tillage practice is such that the entire field is not plowed up in the fall or whenever maintenance is necessary, where erosion is more severe and supplemental maintenance is required between the regular plowing intervals, and where terraces are slightly undersize and additional plowings are necessary to provide adequate capacity. With the one-land method less plowing is required, but proper emphasis is placed on the channel and the undisturbed vegetation immediately below the channel affords considerable protection in case the terraces should overtop during the rainy season.

From the accompanying illustration it will be noted that the first furrow is thrown downslope at the lower edge of the channel. In the Southeastern States the second furrow is thrown upslope 12 to 18 feet from the first furrow. The distance between these two furrows will depend on the slope of the land. When this strip is plowed out, the deadfurrow will fall at the flow line. The outside furrows of this strip should be plowed deep and close, decreasing the depth and increasing the width of cut as the flow line is approached. This procedure will produce a broad-shaped channel.

In Region 2 it has been found that terrace maintenance should begin as soon as fall crops are harvested. Power and labor are available at this season, and in most instances the majority of the terraces can be maintained before January 1. If maintenance is delayed until the spring season seedbed preparation will compete with terrace maintenance and often the terraces will not receive proper attention.

The time when terraces should be maintained will depend, to some extent, on the rotation that is prescribed. For example, if grain and lespedeza are to follow cotton, it will be 2 years before the terraces can be maintained without destroying a strip of lespedeza. In this case, the terraces should be maintained before the grain is planted in the fall. This will ensure adequate channel capacity to control the run-off while the grain is making sufficient growth to protect the terrace interval.



Two-land method of terrace maintenance.

From experience in Region 2, it is concluded that field demonstrations followed by individual contacts give most effective assurance that proper maintenance will be carried out by the farmers. In project and camp areas, the cooperators are called together in each community for a field terrace-maintenance demonstration. Previously the technician has arranged for plows, teams, and drivers. One or two terraces are maintained while the cooperators observe the work. While the plowing operations are being carried on the technician explains each step as it is completed. This gives the technician an opportunity to explain the proper shaping of the channel with horse- or power-drawn equipment. During the demonstration the technician emphasizes the fact that terraces should be maintained before the rush during the planting season in the spring.

Following the demonstration, individual contacts should be made with each cooperator present at the demonstration to further assist him with the details of terrace maintenance on his farm.

Field meetings of cooperators immediately after heavy rains, to study the results of the various erosion-control practices, afford an opportunity to emphasize the importance of proper terrace maintenance. On these group tours, fields should be inspected where terraces have been properly maintained and are functioning properly as contrasted with other fields where maintenance has not been obtained and damage has occurred. This procedure has been very effective in project and camp areas throughout this region.

In conclusion, each technician should understand (1) the details of terrace maintenance and how to assist in obtaining compliance, (2) the use of vegetation and its placement as an aid in preventing silt from reaching the terrace channel, (3) slope and soil conditions under which terraces cannot be maintained economically, and (4) the devices for establishing terrace maintenance as a part of the regular farm operations

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D. J. Gardner, Extension officer for the Union of South Africa, gave the following account of terracing work to a local newspaper, "The Kokstad Advertiser," upon his return from a recent inspection trip to the British Isles, the Continent, and America. He said that terracing went through a period of transition. He had come to the conclusion that if one were aiming at permanency one must build the broad-base terrace. The day of the narrow-ridged type of terrace was gone; they needed the broad-base type and the whole of the terrace must be cropped like the rest of the field. After construction the terrace must be supported by proper strip-cropping, well planned rotations, and generally, good farming practice.

AGRONOMIC MEASURES OFTEN REQUIRE MECHANICAL SUPPORT

By C. R. ENLOW[1]

THE agronomist who has had the opportunity, during the past 5 years, of studying the erosion problems on the croplands and pastures of this country and the agronomic measures that have been employed on soil conservation demonstration areas must indeed be a specialist of narrow perspective if he has not yet learned to appreciate the engineer and the importance of engineering methods in erosion control.

The engineer is anxious to do his part and generally is most willing to give full cooperation to the agronomist, the forester, and the other technicians. He has learned to appreciate the importance of vegetation as a supplement to his mechanical structures. Sod strips to filter out the soil so it will not clog the diversion channels; grass, shrubs, or trees to anchor the soil around a drop inlet, a dam, or a terrace outlet; close-growing vegetation in a waterway to prevent scouring; grass or vines to protect a steep embankment—all these are essential to practical, economical soil conservation engineering.

In planning a soil conservation program, the water disposal system should be the very backbone of the physical problem. When the engineer is required to plan the handling of excess water on scattered farms, without opportunity to make an over-all plan, the advisability of working on a watershed basis immediately becomes apparent. If, as quite frequently happens, a farmer wants a soil conservation plan, and the surplus water from one or more farms above him is rushing across his fields, what should be done? If his farm is to be considered singly, the engineer undoubtedly will be obliged to install an expensive diversion channel (provided he can find a satisfactory outlet for the water) before any erosion-control measures can be successfully employed on the farm. Working on a farm here and a farm there greatly complicates the problem. If the engineering plans for the entire drainage area can be prepared as a single unit the results are more economical, satisfactory and permanent. The engineer, when attempting to plan a particularly difficult water disposal system on a single farm, may realize with misgivings that his professional forebears in the early days laid out this country on the square. Most certainly the fact that we must practice "round farming in a square country" now is a problem for all those interested in furthering the cause of soil conservation, whether they have specialized in engineering, agronomy, forestry, farm management or wildlife control. Certainly the problem is particularly trying for the engineer.

Agronomic methods of erosion control quite frequently must be supported by engineering practices. What agronomist of today would attempt, under the conditions cited above, to control soil erosion by strip cropping without first insisting upon the installation of necessary run-off diversion measures? Many such mistakes were made in the past with the result that engineers had to divert the water by building structures after the strip cropping program was put into effect. The ultimate result was increased costs and much inconvenience to all concerned. It is to be hoped that the agronomist has profited by these mistakes and is insisting that the engineer have an opportunity to contribute in the very first planning.

Approximately 1,000,000 acres of cropland within the boundaries of Soil Conservation Service and C. C. C. work areas are now farmed by contour strip cropping. Today, on many farms where it was formerly thought that contour strip cropping would successfully control erosion, diversion terraces or regular farm terraces are being installed to supplement strip cropping. Why? Merely because we did not know too much about strip cropping, and in our enthusiasm we expected too much from it.

The agronomist who is willing to recommend contour strip cropping to control erosion on a long, badly eroded slope with a distinct erosion pattern already established and the topsoil mostly gone, is being too confident about something he does not understand. Unfortunately there are many such errors on our soil conservation projects today. Under such conditions, engineering work—terraces or diversion terraces, depending on the slope, soil and other factors—should be the framework on which to build. It is impossible to continue to crop such land and improve or even

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Terraces are essential in a badly eroded field with a distinct erosion pattern, to prevent the accumulation of water which would destroy the vegetation. The combination of terraces and strip cropping gives very satisfactory erosion control.

maintain soil fertility without engineering aid. With the terraces to break a long slope into several short ones, to prevent concentration of water into countless depressions down the slope, and to be used as guides for contour cultivation, the chances of success look much brighter. We can scarcely afford to endorse a program for erosion control unless it at least appears permanent on the surface—and the addition of the terraces adds the touch of permanency. If the agronomist has not overlooked mineral deficiencies, a real erosion-control rotation with proper tillage practices, land conditioning for legumes and grasses and some of the other highly important fundamentals of agronomy, the chances that a permanent program will result are much improved. Methods of terrace construction and maintenance have improved tremendously in the past 5 years, and an efficient and conscientious farmer will find little difficulty in the maintenance of terraces that have been properly installed.

Frequently a situation is found where bottomland cannot be properly farmed until erosion from adjoining slopes, whether pasture or cropland, is stopped. If the land is cropland the problem may be similar to that previously described; but if it is in a serious condition from erosion it may be necessary to take it out of cultivation and return it to grass or trees. Under such conditions, contour furrows or terraces are frequently necessary to obtain immediate control while a good cover of vegetation is being reestablished through proper management. It is not uncommon to find permanent pastures on abused and neglected slopes that are erosion hazards almost equal to any that can be found on cropland. Terracing is a necessity and it can be justified on pastureland where valuable cropland is being protected by the same practice.

The value of engineering in water conservation is so generally recognized that comment is scarcely necessary. In semiarid regions, contour furrowing is an accepted practice in preventing run-off and saving the limited rainfall for the increased production of vegetation. If the rangeman can succeed in carrying out a grazing plan that will give the vegetation a chance, his efforts combined with those of the engineer will go a long way in preventing water and soil losses. The engineer's work in constructing dams for watering places, to provide better distribution of livestock and thus prevent overgrazing in areas adjacent to the present sources of water, is recognized as a real contribution to the program.

The agronomist is always ready and willing for the engineer to step to the front when a deep gully is eating its way into a field, or where water must be let down a slope so steep that the velocity of flow is too great to permit revegetation. The disposal of flood waters and of accumulated water from highways, are engineering problems that must be solved before the agronomist can successfully effect his phase of the program. The real test of engineering-agronomic cooperation comes, however, on the sloping eroded fields as previously described, where even the combined efforts of both may be found insufficient to meet the problem of rehabilitating the land for continued and permanent cultivation.

The agronomist working in the soil conservation program has learned to respect the engineer. It is not at all uncommon to hear the engineer emphasizing the importance of the rotation of crops, the advisability of using specific grasses, or the necessity of soil conditioning in order to produce vegetation. Facing practical farm engineering problems, the engineer has shown a versatility that is commendable and a resourcefulness that is admirable.

SOME ENGINEERING ASPECTS OF THE WATER FACILITIES PROGRAM

By H. T. Cory[1]

THE development and construction of water facility projects is being carried out during the current fiscal year under the so-called Water Facilities Act of August 28, 1937. The program is financed by $500,000 included for this purpose in the 1939 appropriation to the Department of Agriculture. The Secretary of Agriculture, recognizing from the experience of the Farm Security Administration that many rehabilitation clients can accomplish their own economic reestablishment if they are provided with loans and technical help for the construction of small water facilities, has allotted $5,000,000 from the emergency relief appropriation of 1938 for water conservation, dams, reservoirs, pipelines, well digging and drilling, and other small facilities for water storage and utilization, in furtherance of rural rehabilitation and relief to needy farm families. As a result of this arrangement, however, certain limitations are now in effect to carry out legislative provisions which are not common to both the Water Facilities Act and the Emergency Relief Act of 1938. The three most important are (1) that no more than $50,000 be assigned to any one project, (2) that projects are to assist farm families of low income, and (3) that Federal funds for construction be loans rather than grants. How profoundly these limitations will affect the administration of the Water Facilities Act after the current year remains to be seen, but for the present they are adequate.

It has been determined, and administrative instructions have been issued accordingly, that allocation of funds for projects and the approval of such projects will be in the hands of a Water Facilities Board composed of representatives of the Land Use Coordinator's Office, the Bureau of Agricultural Economics, the Farm Security Administration, and the Soil Conservation Service. These agencies will formulate and carry out the administration policies while the Soil Conservation Service will execute the program, designing and carrying out the actual constructions. Such an arrangement automatically diverts a large share of the major field responsibilities to the engineers of the Service.

There are two ways of constructing water facilities to assist a farmer under the Federal plan. The Department may decide to supply the funds for a farmer-built facility, accepting a note and arranging for its repayment according to the farmer's ability to pay, the Soil Conservation Service engineers acting only in the capacity of consultants or supervisors of construction. Or instead, the actual building may be done by the Soil Conservation Service, with the financing plan and collections remaining a separate responsibility of the Farm Security Administration.

Loans based upon the construction costs are to be made and approved before any field work is begun. Estimates of such costs are an engineering responsibility and must be reasonably accurate in spite of the unknown factors involved. Farm conservation plans are to be made and enforced as a part of the several projects, but the engineering structures will be the features around which the whole program hinges and their success or failure will determine to a large extent the future of the entire endeavor.

Under the program, loan applications doubtless will be made for projects varying greatly both as to their nature and their cost. Probably no engineer or engineering organization at any time or in any place has been called upon heretofore to treat with such a diversity of projects, hydraulic in their nature, as will confront the Soil Conservation Service engineers. Allotments will be made for installation or construction of facilities which will provide livestock or irrigation water; collect supplies from precipitation, springs, water tunnels, underground streams and reservoirs, and surface sources; recharge subsurface water-bearing strata; and run the complete gamut of water storage developments. The facilities must also have useful lives of predetermined duration and they will entail a tremendous variation of costs per quantity unit of utilizable water output.

Thus the task imposed upon engineers for designing and constructing or supervising the construction of

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water facility projects will be out of all proportion to the relatively small total expenditures. There will be no glamour of monumental size, of large scale mass production adaptations amounting to inventions, or of tourists detouring from main thoroughfares to see marvels of engineering. It will all be comparatively drab work. Yet much of it, to be well done, will require the highest type of engineering ability.

This is peculiarly the case because the immediate beneficiaries must, to the limit of their capacity, repay with interest the Federal funds going into projects, overhead excepted. It is not a matter of spending other people's money and "doing it right regardless of expense," but of handling jobs as trustee for a lending agency on behalf of a borrower who through lack of funds must place operations for his particular benefit unreservedly in the hands of such lending agency. All borrowers will probably be in the low income farmer group, and a little added bad fortune or unnecessary expense may destroy entirely their insecure status as independent farm operators.

Thus it is that mistakes as to designs, as to results obtained, as to estimated costs, as to useful lives of structures, and as to maintenance and operation expenses must be at an absolute minimum. Otherwise, in addition to much avoidable mental anguish, black marks will be chalked up against a movement of social import designed to help some of those struggling to retain their economic independence. From these several considerations one may obtain a realization of the peculiarly exacting responsibilities which the immediate water facilities program places upon the engineers who will be called upon to design and construct water facility projects.

These projects may be classified in a good many ways—as to purpose, sources of water supplies, structural means of securing desired results, etc. There are several equally important features of the engineering work, viz, designs of works suitable to the requirements and conditions, organization, labor, decisions upon equipment requirements, proper machinery and materials, supervision of construction work, etc. In this résumé, however, only the design aspects of projects classified as to supply of (1) underground waters and (2) surface waters, will be considered.

The amount of water which for any length of time can be obtained from undeveloped underground sources is never accurately predictable and often only within very wide limitations. Much the same is true regarding depths to water-bearing strata. Unfortunately, the common idea that continuing small seeps of water from hillsides and swampy areas can be "developed" into yielding significant amounts of water often proves erroneous. Nevertheless, tunneling and other enlargement efforts sometimes greatly increase the water yield. The local geology is the significant feature. Since few engineers are experts in geology, and since most Soil Conservation Service regional staffs include at least one and sometimes several specialists in geology, their opinions should be secured before starting to develop water seeps. Much the same is true as regards wells. Hard or even slightly brackish water is better for domestic livestock use than water hauled long distances. Therefore water quality, excepting surface pollution of course, is usually a minor consideration with respect to water supplies for this purpose; the chief considerations usually are necessary supply and the least expensive casing and pumping equipment for satisfactory and lasting use.

Usually, wells for irrigation water supplies must yield relatively large amounts of water—0.5 cubic foot to 4 cubic feet per second (225 to 1,800 gallons per minute). Except in proved areas, the output and "drawdown" (the depth to which water in the well is lowered while pumping) are seldom predictable except within wide limitations, a fact which should be impressed upon all concerned, especially the borrowers for such types of water facility projects. Drilling wells for large water yield is a very specialized business, and capable contractors usually are conservative both as to advance yield estimates and unit prices for work. Probably of all engineering activities which are susceptible to contract, well drilling offers the greatest complications in complying with governmental regulations as to contract work and, at the same time, in securing good work at low costs. If, as may well happen, the water facilities program as tentatively approved includes drilling many wells scattered over an immense area, the Soil Conservation Service engineers will face a situation without precedent. In such a case the methods and procedures used in getting well-drilling work done will be watched closely by a large group of the country's technical men.

Another interesting fact is that it will be necessary to estimate the useful life of the well. Estimating the useful life of a well is by no means common. It involves estimates, it is true; but it also involves guesses as to quantity of water which will be collected, amount thereof which will get back into the local water-bearing strata, total accretion to and depletion of the underground water body tapped, probable change and rate of change in water quality, corrosion rates of well casings, plugging of well casing perforations from several causes, caving in, sanding up, etc.

Relatively few wells will be artesian, that is, flowing.

Water must be pumped from those which are not. A complete well unit is often considered as including not only the well, but all the pumping machinery and related power plant. Nevertheless, water wells and the pumping plants to take water from them belong to quite different classes of engineering. Wells may safely and continuously yield much more water than the pumping installation can handle and vice versa. The output of the complete unit is determined by the capacity of the minimum controlling element, hence it is important that the two should be properly balanced for economical and satisfactory results.

To secure such balance is not simple. The completion feature of sinking a well is the testing of the output for a continuous yield of 24 to 72 hours. It is not practicable to require a longer trial period, and usually portable pump outfits are used for such tests. Only after the results of such tests are known can an intelligent judgment be made as to the capacity and type of the permanent pumping equipment which should be installed. Even then the water output may gradually increase or decrease for a long time and thus throw the two parts of the total installation out of balance.

The type, efficiency, and durability of pumping equipment are exceedingly important. Most pumps, and power units driving them, have high efficiency over narrow ranges of quantity output, but this efficiency decreases rapidly when the work is either lessened or increased. This is an added reason for careful balancing of the equipment to the water yield. Also, there are sharp differences in the durability of pumps and especially of pump runners, if any sand is carried by the water.

Nevertheless, it is necessary to make advance estimates of the total cost; and, on such estimates not only must both the farmer and the Federal agencies decide upon the desirability of projects, but also through them obligations must be executed by beneficiaries before work is started. If advance estimates are too high, desirable projects may be rejected as too costly, and if too low the deficits must be made up from Federal funds.

In planning for the storage of surface waters, the designing engineer is always confronted with three chief dangers quite unlike the considerations he takes into account when planning for well installations. These are (1) overestimating the amount of water which can be caught and retained, (2) underestimating the size of great floods and (3) underestimating deterioration, particularly from silt deposition.

A reservoir which becomes empty or nearly so during droughts is an asset of questionable value, although it may be better than none at all. Nevertheless, few things are more disconcerting than a water supply which fails when most desperately needed. The so-called "wetness" of years varies greatly, as do the cycles, so that for periods of several years the rainfalls are subnormal; the evaporation is excessive and the watersheds become thirsty and absorb much and often all of the very little rain which does occur. Furthermore, a larger drainage area than necessary means greater and perhaps excessive spillway costs. Variations in the water yield from relatively small watersheds may be almost unbelievably wide, and engineers and others who refuse to accept the relevant data frequently make gross overestimates of the amount of water which can be collected in critical periods. The danger is less with larger watersheds, as these usually have stream-discharge records extending back from 10 to 50 years.

Most small water storages are created by earthen dams which if overtopped by floods are damaged or completely destroyed. Intense, short, local rainfalls of the cloudburst variety are characteristic of arid and semiarid regions. It is only a question of time when such a storm will occur over any given small drainage basin within the region where water facility projects will be built. Present knowledge of such matters is so meager that the designing of spillways around earthen dams, for effective protection and yet not prohibitive in cost, is a grave problem. It tests the capacity of hydrologists to the limit.

Sometimes such spillway problems may be avoided if the storage reservoir is located quite outside the main drainage basin and where there will be a very small water collecting area upstream from it, and if the water is conducted to the reservoir through a supply canal heading in the main stream. Such a treatment will prove desirable where the supply canal can be short and cheaply built, and the diverting works on the stream whose waters are to be diverted can be simple and inexpensive. Since in a good many instances ordinary spillway provisions will represent as much or more than half the total cost of storage facilities, the possibilities of off-stream storage will frequently merit investigation. Again it is a matter of judgment. Indeed an unusual amount of the engineering work on water facilities projects will not lend itself to determination by formula and mathematical examination.

The ultimate destiny of all reservoirs storing surface run-off is that they will be filled with silt; the only question in any given case is how long a time will be required. The useful life usually will be considerably

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IRRIGATION AND THE CONSERVATION OF THE RANGE

BY W. W. McLAUGHLIN[1]

NEARLY all life—human, animal, and plant—depends for its sustenance upon air, food, and water. Of these three essentials, water is the scarcest in the western part of the United States, and consequently the controlling factor in food production. The whole industry of the arid region is built around and must be limited by the water supply. Our problem thus resolves itself into the utilization of the water supply for the greatest good to the greatest number, and the question of land use becomes in a measure secondary to that of water use.

In the planning of range conservation and irrigation, there are two aspects of the question that must be given full consideration. These are (1) the principle of long-time use planning, keeping in view the greatest good to the greatest number, and (2) the immediate aspect and the individual human benefit that cannot be divorced from the picture. In other words, we cannot disregard the immediate future in planning for the ultimate future. Neither can we place too much emphasis on the academic planning, unless we first give serious and justified consideration to the practical application and consummation of the plan.

In considering the utilization of our water supply for the conservation of the range and for irrigation, we must be ever mindful that the problem is dynamic and not static. Changes have occurred in the past and will continue to occur as a result of changing economic conditions. Changes in climatic conditions are also important. It must be kept in mind that there may be a more important use of water than for aiding in the maintenance of the range, and even for irrigation. Water is demanded for municipalities, for industries, for farming, for grazing, for wildlife, and for recreation. In nearly every State a preferential right to the use of water is specified, the first right being that of human consumption, then agriculture, then industry, etc. But a force even greater than these legal restrictions develops in the economic conditions resulting usually from increased population, increased industrial activity, and other demands which can afford to pay more for water than can the range or the farm.

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In what ways are range conservation and irrigation interdependent? The problem has been stated thus: In the range areas of the West how many acres (10, 40, or even 100) of rangeland is necessary to maintain one animal? But, in the irrigated section the question is asked quite differently: One acre of irrigated land will support how many animals? On the range, for the most part, there is a time of the year in which the animals cannot be grazed, and fodder must be provided from some source to maintain them during this period. Under the Taylor Grazing Act, and the Forest Service regulations, one of the limiting factors to the number of animals that may be grazed is the amount of feed the applicant produces for the "winter carry-over." This feed in the West is grown for the most part under irrigation. In years of unusual drought, such as 1934 and 1936, there was practically no feed produced on the ranges in several regions, and it was necessary to dispose of the animals or to move them where feed could be found. This meant usually moving the animals to an irrigated area. There is a limit to the distance animals can be moved with profit, and there is a limit to the distance to which feed can be moved. It naturally follows that to make the best use of the range it is desirable to have feed available within a reasonable distance of the range. Likewise, in order to enhance the carrying capacity of the range it is necessary to increase the amount of feed the range is now producing.

Range management and irrigation agriculture are closely related in much of the West, yet the livestock grower has often looked askance at the prospect of farming the land intensively. He knows that it must be done for his own good; but is willing and eager to leave it to someone else. In common parlance, he prefers to "farm on horseback." So we find various communities in which the livestock growers have engaged in irrigation farming as a necessary evil, to provide the feed which they need to supplement the range.

Kanab, Utah, with its limited irrigated agriculture centering around and absolutely subordinate to the dominant livestock industry, typifies such a situation. Many other examples of the relationship between live-

stock production and irrigation agriculture might be cited. The Vale irrigated area in eastern Oregon is a typical area in which an irrigation project supplements the ranging of livestock. In Colorado and western Nebraska, as elsewhere, feeding of livestock is an essential part of the irrigation project economy.

There are two major possibilities for the employment of irrigation in the conservation of the range. First, there is the irrigation of the range itself, which of necessity would be very limited in extent as well as spotted in most regions. The second possibility—and we might say necessity—is the creation of more irrigation units to be coordinated with the utilization of the contiguous range.

In the first possibility, there is little likelihood of there being anything spectacular done, since the works required are of minor engineering importance, although in the aggregate the increased fodder production may be in many areas most significant.

For example, there are many areas where flood water flowing down broad valleys or coulees can be diverted, and the water so diverted let flow where it will, or directed by inexpensive and usually short ditches over bottomlands adjacent to the streams. The areas that lend themselves best to this type of development are those in which there is relatively little fall to the lands or to the stream. In the plains area, an excellent example of this type of irrigation is to be found on the Souris River, in north-central North Dakota. There are numerous instances throughout the West, in areas which for the most part will probably always be used for grazing, where this practice could be effected and the amount of fodder greatly increased. In years when the range affords ample pasturage, these flooded areas could be cut for hay and thus a reserve of feed built up for years of drought.

In many mountain valleys, especially in the upper parts of the watershed, it is possible that the diversion of flood water on to less steep grazing areas would serve a double purpose of increasing the fodder growth and reducing the spring run-off of water. There are also many upland meadows where improvement could be made in the fodder production, through a limited amount of drainage coupled with the diversion of water from the natural channel around the edges of these meadows. Some of the small upland lakes could be made into reservoirs, and their waters released later in the season for irrigating the upland pastures. The water from springs likewise could be distributed, and while the total area so covered with water might not be great, yet one acre of partially irrigated land would produce many times the amount of fodder grown on one acre of nonirrigated range. Some of these upland reservoirs, when so constructed, might be utilized to develop a small irrigation unit within the grazing area itself. In some parts of the range water holes and small reservoirs for stock-watering purposes could be constructed, and when properly located throughout the area would tend to prevent overgrazing of areas immediately contiguous to springs, running streams, or the occasional water hole.

In some areas, for instance in parts of Nevada, the Great Plains, and elsewhere, there is to be found underground water which may be pumped and used either for the irrigation of limited areas of land or for the creation of facilities for stock watering. While some of these developments, especially those involving underground water, may within themselves seem prohibitive in cost, yet when considered in conjunction with the range they may be found entirely justifiable from an economic standpoint.

I often recall an incident that happened some years ago when a stockman called at my office in Berkeley, seeking our assistance in designing a pumping layout to irrigate some 40 acres of land in the High Sierra which was to be seeded to alfalfa. The pump lift was to be about 130 feet. My immediate reaction was that the lift was too great, and consequently the cost of producing hay beyond the economic limit. But this sheepman soon convinced me that it was much cheaper to pump water 130 feet to grow the small amount of feed necessary to carry his flock over than to ship the sheep out or ship hay in at $30 per ton.

However, the principal place of irrigation in the conservation of the range is its practice in a truly irrigated area. As previously indicated, neither the stockman nor the dry farmer adapts himself readily to irrigation farming. The irrigation unit provides fodder for the range stock, not alone to carry them through the winter and through drought periods, but to provide both hay and grain for the fattening of animals for the market. The range animals afford the irrigation farmer a market for at least a part of his produce.

In our recent survey of the San Luis Valley in Colorado, which was originally and entirely a livestock country, we found that out of some 600,000 acres of irrigated land about 283,000 acres was in wild hay and pasture, and, further, that this wild hay and pasture is irrigated almost entirely with flood water. But it is irrigated.

One phase of range maintenance and conservation that has been more or less disregarded is that generally spoken of as supplemental irrigation. The fact that this has been largely neglected may be attributed to

the antipathy of the stockmen toward farming, even to the extent of raising a family garden. "Supplemental irrigation," as here used, includes providing water with which to maintain the family garden and orchard, the raising of sufficient fodder for the family flock and herd, a few pigs, and the work stock. With such an irrigation layout the family is assured, even in times of extreme drought or some other range disaster, of sufficient food for themselves and feed for the operating livestock and poultry. It can be, and often is, a source of considerable income and, of course, is most valuable when prices for range stock are low or when for any other reason the profits from the range are lessened. This type of irrigation in conjunction with the range should be given much greater consideration in the future planning than it has received in the past.

It is not to be understood that any of the above practices can be entered into promiscuously, nor should the building of small diversion dams be undertaken or permitted in connection with the development of a range, until due consideration has been given to the relation of the particular dam to other developments within the range. There are instances where too many diverting dams have been constructed with improper guidance in their building; and too many small reservoirs have been constructed in too steep ravines or canyons and in dry washes. Mere storing of water in ponds without some definite use of the water so stored is not true conservation. In some areas, large numbers of dams have been constructed with no means of utilizing the water, which is simply allowed to evaporate. The conservation of the range presupposes coordinated planning, and that is essential in any development.

North Dakota's plan to rehabilitate the agriculture in its drought area is interesting. The western part of the State is devoted almost entirely to stock raising and dry farming, both of which were almost wiped out during the past 4 or 5 years of excessive drought. The last legislature of the State created a water conservation commission and made available to them $112,500 for the next 2 years to lend for the purposes of irrigation. The Bank of North Dakota made available $50,000 for the same purpose. With the thought that the irrigation projects in mind would serve as demonstrations, the bank loans are limited to $1,000 and apply to areas of not more than 40 acres each. In the discussions and deliberations incident to the inauguration of this program, there was always brought out the coordination of this irrigation development and the livestock industry.

I have indicated in this paper that the range as it now exists is not stable, and I wish to call to your attention another particular in which there is likelihood of a change in our present grazing privileges on the range. In the arid region we must admit that the greatest natural resource is water. Anything that affects the water yield, either in quantity or in seasonable yield, has its effect on the value of that natural resource. In most of the West the area from which water is derived for all purposes is the watershed, usually in the high mountains. Therefore, the proper use or the abuse of this area is of vital importance to the water user, and I venture the statement that it will not be long until the water user demands and insists upon a voice in the control and use of the watershed. This means a voice in the control of grazing. Already in some few areas the water users have acquired title to the lands of the watershed. In others they have gone so far as to demand the discontinuance of some practice or practices that interfered with vested water rights. I do not see in this regulation of the use of the watershed anything especially antagonistic to the conservation of the area as a range for livestock, but it would certainly preclude the abuse of the grazing privilege.

SOME ASPECTS OF WATER FACILITIES PROGRAM

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less than the period required for complete filling by sediment. The establishment of adequate soil conservation practices in connection with all water facilities projects should materially increase their useful life. Thus, several factors must be evaluated before the final answer can be had as to the useful life of water facility projects which involve storage for surface waters. Each of these factors is largely a matter of experience and the final answer even more so.

In general, the smallness of such works introduces a different set of criteria and data than those which have been used for large works in the past. Practically speaking, engineers will break new engineering paths in designing and constructing a host of small water facility projects for surface-water storage and utilization. Only a couple of years ago the expression "upstream engineering" was coined for an essentially new type of engineering activity; namely, one dealing with hydraulic, hydrologic, and erosion problems on small watersheds. It now seems that, in carrying out their responsibilities in the water facilities program, conservation engineers may develop a new engineering field which will merit the cognomen "water facilities engineering."

ENGINEERING PLANNING IN FLOOD CONTROL

By E. R. Kinnear[1]

THE scope of this subject is very broad and the space allotted limits the discussion to a brief analysis of flood-control planning within the policies of the Department of Agriculture.

The increased interest in flood control and related water problems has recently inaugurated extensive drainage basin studies which indicate the necessity for greater refinement and consideration of detail in comprehensive flood-control planning.

The watershed details with which we are most concerned are land use and management, soils, vegetation, sedimentation, flood flows from tributary streams and a more complete consideration of economic values. To evaluate properly these details in relation to flood-control planning we must have qualitative and quantitative analysis on a watershed basis. It is logical that surveys and planning should be carried out on a watershed basis, since a flood is a concentration of water and its accompanying sediment load occurring at a given point within a given time and resulting from the actions and interrelations of these elements on the given watershed.

It is essential that hydrology, sedimentation and economics—foundation stones upon which any flood-control plan must be constructed—be based upon all known measurable and constant factors. The unknowns and variables should be evaluated by the most acceptable technical procedures available. The differences of technical opinion as to procedure, and the permissible tolerance of accuracy in results, must be molded together. In some instances, long-time studies may be required in order to strengthen some of the approximation. In this manner, we can evaluate land use, water conservation and flood control in specific terms. Since erosion control and flood control are both economically subservient to land use, flood-control practices and supplementary works as designed and evaluated for the interest of the individual farm or area may be modified for the best interests of the watershed as a whole.

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A comprehensive flood-control plan will involve nearly all human activities pertaining to land and water use. Thus it appears that a sequence of steps for formulating a flood-control plan should be indicated. It is suggested that an orderly approach is as follows:

1. Accumulation of physical and statistical data and an accurate classification and evaluation of damages.
2. The classification and evaluation of the elements contributing to damages.
3. The planning and designing of the most economical control practices for the prevention or amelioration of the damages.
4. The coordination of agricultural flood-control planning and designing with all other flood-control or water-use plans or developments in the watershed.
5. The evaluation of the benefits accruing from practices in terms of reduction of potential physical and economic damage.
6. The evaluation of the indirect benefits which would result from the establishment of control practices, with consideration of the long-time land-use and social problems within the watershed.
7. The balancing of the cost against the total benefits derived.
8. The determination of a suggested sequence of operations with allocations of budgeted amounts over the required period of years, looking towards a projected date of completion; and the determination of the most economical method of financing the construction of the control measures, giving full consideration to the private, State, and Federal interests involved.

It is apparent that a negative conclusion as to the feasibility of a plan may possibly be reached at any point in this procedure, or that a positive conclusion may result all the way through.

We are accustomed to think of floods in terms of damage which usually takes the form of erosion, sedimentation, physical damage by water or loss of life. This damage is generally expressed in terms of money or retardation of development through a sense of fear and insecurity which results in social detriment. The classification and evaluation of flood damages of record, and the analysis of the factors which produce each type of damage at each locality require a comprehensive and thorough study of the hydrology, sedimentation, and economics within the watershed—this in order that the extent and magnitude of potential damages may be more accurately estimated. A thorough physical and economic appraisal of past and potential flood and sediment damages is necessary for the entire watershed and is of primary importance. A segregation should be made between those damages

caused by outstanding individual floods and those caused by numerous minor floods which are progressively destructive over a long period of time. The results of this appraisal will aid in determining the extent to which the additional physical and statistical surveys should be carried out.

These surveys will provide the data which are the tools that engineers must use to build up the plan for flood control. We can only briefly indicate here some of the indispensable basic data.

1. *Physical characteristics of the watershed.*—Sufficient information must be obtained to evaluate the topography, geology, soils, erosion, vegetation, and sedimentation with respect to their influence on the flood problem. From topographic maps, aerial photographs, geologic maps and data, we may determine the influences of these characteristics on surface run-off, ground water, erosion, and sedimentation. Detailed cross sections may be required for existing or proposed dam sites and reservoir capacities, and locations of other structures. Sedimentation cross sections and profiles of reservoirs on stream channels may be required.

Conservation surveys should provide pertinent information on soils, erosion, and cover. Soils information is of utmost importance—such as soil moisture (cyclic, seasonal, and associated with storms), infiltration rates and storage capacity limits; erosion characteristics, physical and chemical characteristics, and limitations with respect to vegetative productivity and its influence on maintenance of structures and channels, and soil-mechanics limitations for use of soil in earth structures. An appraisal should be made of permanent or semipermanent damages to soils—or the crop base—within the flood plain with respect to scour, bank erosion, sediment, and debris deposition.

2. *Meteorology and hydrology.*—Meteorologic analysis and synthesis for storm patterns will be required. Climatic characteristics in terms of the cyclic and seasonal variations and conditions to be expected during storms must be evaluated as to temperature, snow, ice, or frost. This knowledge is basic to the calculations of the relations between precipitation and run-off. The same may be said of the character of precipitation and its distribution—the cyclic, seasonal, and storm pattern characteristics, particularly the sequence of rates, areal extent, storm paths, and frequencies of occurrence.

From this information, the engineer will be able to make further determinations which will serve as a basis for actual design. Such determinations are:

1. The evaluation of channel and streamflow conditions with respect to the interrelation of loading of streams, pondage, and hydraulic efficiency of conveyance channels (outside the zone of Army interests or within the zone if cooperatively studied).

2. The utilization of sediment production indexes in the watersheds, to evaluate past and potential damage to existing and proposed storage and flood-control reservoirs.

3. The correlation of specific damages with specific causes, to determine critical flood- and sediment-source areas and to develop the requirements for land-use readjustment, reforestation, soil conservation, highway and streambank protection, and additional mechanical flood-control works.

4. The expression of this information in hydrologic terms with respect to surface inches of run-off and surface inches of storage of flood flows as reflected by hydrographs of the "official plan" flood flows—those representing maximum phenomena against which provision can reasonably be made.

5. Evaluation of these data with respect to financial and other benefits to be derived by reduction of the flood peaks and damages, as a basis for selecting the final design of control measures.

With such basic information available (and whatever additions may be feasible) the engineer, economist, and associated technicians are in a position to evaluate the characteristics of flood-source tributaries. The flood-control relationships with land use, erosion control, water conservation, and forestation, as supplemented by feasible mechanical storage or detention structures, may be developed from the basic information as a basis for design.

Erosion-control practices and supplemental structures should be so designed as to accomplish optimum soil stabilization with maximum flood regulation. In designing structures, under the water facilities program, consideration should always be given to the possibility of modification of the design to provide added spillway storage to effect a measurable delay in the time of concentration and desynchronization of flood run-off.

A few examples may well be considered. It may prove desirable to redesign spreading dikes, terraces, ditches, contour furrows, and similar structures in order to provide a measure of flood regulation. Such redesigning is limited, however, by the allowable inundation time of the crops or vegetation involved, and by the value of the vegetation either as a crop or as a maintenance factor. In this, soil drainage is a pertinent factor.

There may be instances when land-use practices alone, such as strip cropping and grassed waterways, are sufficient to achieve optimum erosion control.

Permanent pasture may achieve optimum erosion control, but the installation of large water-spreading ditches and terraces on the pasture would provide a valuable measure of flood storage and delay in time of concentration. Such possibilities may often be limited by land-use economy, time of inundation of vegetation, climatic conditions, and other factors.

In certain instances the redesign of highway and railroad drainage may be an important contribution to flood control; but it must be considered always on a basis of economy as influenced by flood frequencies and damages involved.

There are areas where flood run-off from land of extremely low value and utility is causing severe damage to valuable lands below. Such areas may require land zoning and appropriate restrictions plus detention dams, mechanical controls which may cost more than the land is worth even though this cost may be well within the limits of the total economy involved.

There are instances where streambank and flood-plain erosion may not be affected by reduction of flood peaks, so that no modification in standard design for maximum flood conditions would be permissible.

In order to determine the technical feasibility and efficiency of a flood-control program on a quantitative basis, it is essential that some measure be used for drawing a comparison between existing conditions and the proposed controlled conditions. The assembling and routing of flood flows by the flood hydrograph method is a valuable yardstick currently used by engineers. This is applicable to individual structures from the small headwater areas, progressively to the whole watershed area, and such findings reflect the characteristics of flood flows under existing conditions and the probable characteristics of flows under controlled conditions. In both instances, the hydrographs may be based upon the characteristic maximum or official-plan storm for the watershed, which is determined from the meteorological data.

It is probable that all practices and structures will not be designed for the "official storm," since economy and common sense dictate that lesser storm frequencies be used for the design of certain types of practices and structures such as terraces, check dams in gullies, etc. However, the effects of all practices and structures during official-storm conditions will indicate their influence on sedimentation and flood flows.

In flood-control planning it becomes the duty of the engineer to use the basic information outlined in the previous paragraphs as a basis for estimating the rate at which excess flood waters will be delivered as a flood wave from tributaries and, in turn, progress through the principal channel approximating a synthetic flood hydrograph. Hydrographs of flood flows should be prepared for all characteristic sub-areas, both with and without control measures. These flows should be routed in turn and progressively from the tributaries into the principal channel through the points on the watershed at which it is desired to determine the economic benefits. Wherever a flood detention or storage structure is located, the flood reduction benefit of such storage will be reflected in each succeeding hydrograph during the routing process. Thus the cumulative benefits in actual modification of flood flows will be demonstrated. This assembling and routing will offer a basis for evaluation of the control program in terms of reduction of flood crest as affected by delay in time of concentration and desynchronization of tributary flows. It is necessary also to consider the silt loading of the hydrographs, as this affects the regimen of the stream or conveyance channel. Future conditions of the regimen may be indicated through increases or decreases in channel storage and conveyance capacities. Ground water and base flows can be shown in the hydrograph presentation.

The degree of accuracy with which the hydrographs may be prepared will depend upon the ratio of constant and measurable data and records to approximate data in any given watershed, both of which, in turn and in part, may depend upon the accuracy of the surveys.

The carrying out of these planning procedures in a complete manner should enable the engineer, economist, and associated technicians to formulate an estimated schedule of sequence of construction and budgeted costs over the required period of years. This schedule may be used to balance the costs of the engineering and other features of the flood-control plan against the benefits to be derived. Conclusions may then be reached as to whether or not the over-all flood-control plan is technically feasibile and socially warranted.

Farmers' Bulletin No. 1789, "Terracing for Soil and Water Conservation," has had a record distribution since its release last spring. A distribution of almost 100,000 copies in 7 months marks it as one of the most popular bulletins that has been issued by the Soil Conservation Service. It is a compilation of the best information now available on terrace construction and its coordination with other recommended soil-conservation practices. This bulletin should lead to a more efficient use of terracing and a better understanding of its place in a complete soil-conservation program

EQUIPMENT PROBLEMS IN CONSERVATION WORK

By G. E. Ryerson and William X. Hull[1]

THE establishment of adequate erosion-control practices throughout the country is such a tremendous undertaking that it is imperative the work be done as efficiently as possible. This is true regardless of whether the method involves a shifting of crops and the establishment of rotations, or the construction of protective structures such as terraces, dams, contour furrows, etc.

The demonstration projects have served not only as demonstrations of practices to the farmer, but they have also been a proving ground for the development of efficient ways and means of establishing the necessary practices. Unfortunately most of this experience has been gained with large equipment. There is still need for further development in accomplishing the same results with machinery ordinarily available to the farmer.

As more and more demonstration projects complete their programs, the type of work done by the Service is constantly changing. The field of activity is expanding rapidly as conservation districts are established, and as water-facilities and flood-control programs are set up. This changing picture involves a spreading of the activities over such large areas that the most effective utilization must be made of all available equipment, if the necessary work is to be completed within a reasonable time—this regardless of whether it is owned by the Federal Government, by States, counties, districts, private contractors, or farmers.

Even with the efficient utilization of all available equipment, more will often be required to carry out the additional work under the jurisdiction of the conservation districts as they are formed. Equipment needed by the districts may be acquired by loan from Federal or other agencies, by direct purchase by the districts, through cooperative purchase by the farmers of the district, or purchase by the county or other local government or by private contractors.

Regardless of how the equipment is acquired, it is necessary that it be carefully selected for adaptation to the work. Analysis of the job should be made with special consideration for the nature of work to be done throughout the year, amount of equipment shifting necessary and length of such moves, amount of work to be done, the rate at which it is desirable to accomplish the work, peculiar soil conditions which preclude the use of some types of equipment, and the training and experience of the personnel who will operate the equipment.

Many farmers may find it cheaper and more satisfactory to do a large part of the construction work themselves. This should be encouraged especially if farmers can build terraces and construct dams more cheaply, because not only is the necessary cash outlay reduced to a minimum but the landowners develop greater personal interest in the structures and their proper maintenance.

In developing the work plans for the operation of any unit of heavy machinery, a sure and quick means of collecting must be developed. One possibility is to require the farmer to sign a note, prior to the accomplishment of the work, for an amount equal to the cost estimate for the job, collection to be made after completion of the work, either from the farmer or by discounting by a local bank. Another possibility is payment of the charges by the local government and collection through a tax on the land. This plan would require legislation in most States, but has the advantage of allowing the work to be paid for as it produces additional income for the landowner.

Even after satisfactory methods of financing the equipment are developed, it is necessary that the work be adequately planned and that the equipment be kept in operation as much of the time as possible. This may be done in communities where both terraces and dams are to be constructed, by shifting the work to terrace construction during that part of the year in which the land is free from crops, and to dam construction and other activities during the remainder of the year. Where the major portion of the work consists of terracing, it might prove advisable to develop a seasonal price scale, charging a higher rate while the land is free of crops and a reduced rate during the balance of the year. Furthermore, work should be scheduled throughout communities to avoid unnecessary moving about of heavy machinery.

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The equipment itself must be efficiently managed by well-trained and responsible operators who will operate it at its optimum efficiency without misusing or abusing it and who will provide it with adequate care and maintenance. This will require payment of good wages in order that trained operators are retained. In fact, it may be advisable to put these operators on a wage scale one and one-half or two times that prevalent in the community for similar work, but to allow no pay for layoffs, through breakdowns, thus encouraging proper care of machinery. Efficiency in the operation of equipment can be obtained only by some such system.

Tillage Machinery

All erosion-control measures are for the purpose of conserving the productiveness of the soil for future needs. The measures recommended oftentimes are objected to by the farmers because they fear interference with their farm operations. These fears may be either real or imaginary. Any erosion-control measure which changes or alters the farm operations may be a real hardship if the farmer is forced to develop a new technique in performing his normal operations. The recommended practices may also interfere with the operation of the farm equipment. This condition is recognized by most of the Service technicians in that the practices are often tempered by the equipment available on the farms. For instance, size of terraces varies considerably between the farms in the Piedmont Plateau and those in the Black Belt of Texas. This variation in size is due largely to the machinery commonly used in those sections. The width of strips may also be widened in communities where large and cumbersome units are commonly used. Changes from erosion-promoting to erosion-resisting crops and the development of rotations may not be possible, where suitable equipment for handling these new crops is not available on the individual farms or in the community.

The problem of providing suitable equipment to correct a deficiency on individual farms, or even within communities, is not particularly serious as farmers will procure equipment in one way or another if they are convinced that the measure requiring new machinery is economically sound. Of much greater importance is the fact that the farmers lack experience not only in operating the needed equipment but in performing farm operations in the manner necessary to control erosion.

Any limitations placed on the methods in which farmers may perform their normal operations must necessarily reduce the efficiency of those operations unless new and more efficient means are devised. The endeavor to meet this problem has so far resulted in a modification of erosion measures so that farm operations are interfered with as little as possible. In many instances, there is some sacrifice of erosion protection in this effort to prevent too much interference with the farm work.

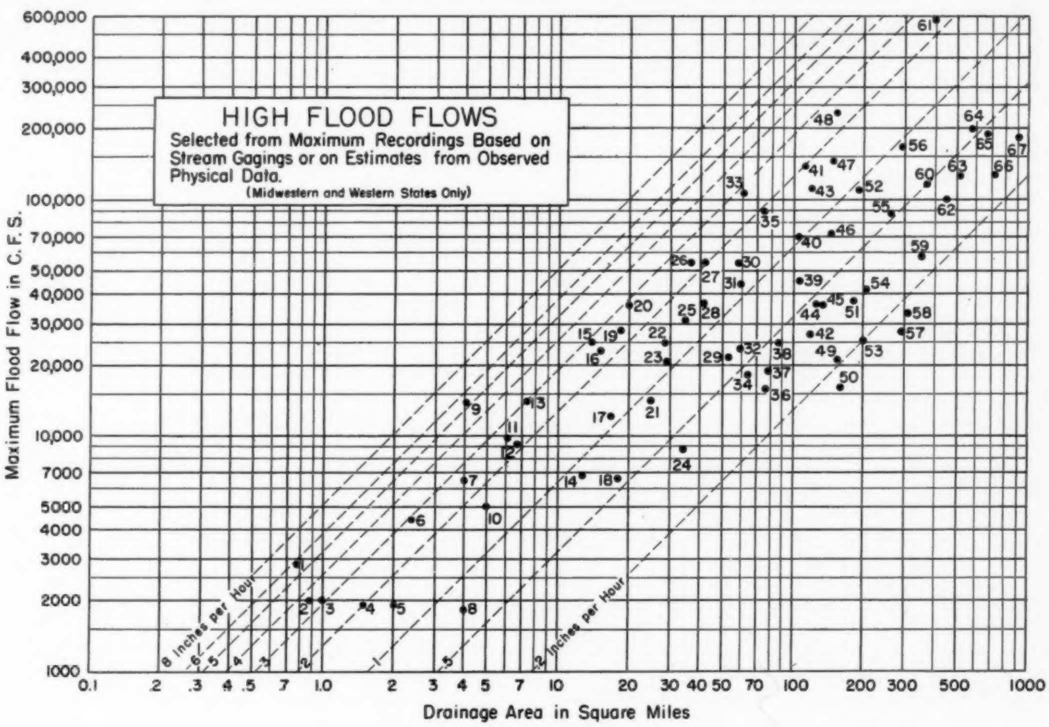
So far as is known, no consideration has been given to the mechanical movement of soil by the tillage implements. Any tillage implement, when operated either down the slope or across it, will move more soil down the slope than up. This, in effect, is the same as erosion. A moldboard plow will not only throw more soil down the slope than it will up, but will throw it farther. A disk harrow also causes considerable movement of soil down the slope. These contour operations, when coupled with erosion, tend to produce a benching effect.

The only method, thus far attempted, of preventing benching is to so regulate the placement of lands that the downward movement of soil is uniform. The value of special implements such as two-way plows and disks has not been fully explored. It is possible, for instance, that the use of a two-way plow would nullify much of the soil movement caused by erosion. It is also possible that terraces could be reshaped to almost any desired cross section within a few years at practically no expense, since it would involve merely the controlling of a normal operation. This would permit the elimination of most of the difficulties encountered in operating other implements on terraced land.

In the production of row crops under a system of contour farming four methods of row placement are advocated by various technicians. These are (1) placement of the ends of point-rows in the terrace channel, (2) at the base of the terrace ridge, (3) at the center of the terrace interval, and (4) elimination of point rows by placing the irregular areas in the strip devoted to the production of a close-growing crop.

No study has been made to determine the cost of turning at the ends of the extra rows which must be done when contour farming is practiced. There is therefore no way of telling which of these methods is most practical. No data are available concerning crop destruction in the turn areas, that caused by side-slippage of the cultivator, crop losses caused by poor control of weeds due to side-slippage of the cultivator, or of losses resulting from uneven depth of planting over the terrace ridge.

(Continued on p. 184)



Key No.	Stream and location	Discharge per sq. mi. in c. f. s.	Year
1 [L]	Pasadena Glen, at Falls, Calif	3,589	1938
2 [L]	Rubio Canyon, at Rubio Falls, Calif	2,273	1938
3	Skyrocket Creek, Ouray, Colo	2,000	1923
4	Magpie Gulch, near Golden, Colo	1,270	1923
5	Cherryvale Creek, at Cherryvale, Kans	930	......
6	Missouri Canyon, at Mouth, Colo	1,810	1923
7 [J]	East Hay Creek (Washita Basin), Okla	1,590	1934
8	North Canyon, Centerville, Utah	450	1923
9 [G]	Bunton Branch, near Kyle, Tex	3,370	1936
10	Hull's Gulch, Boise, Idaho	1,000	1913
11	Hogan's Gulch, Eden, Colo	1,580	1904
12	Blue Ribbon, Pueblo, Colo	1,360	1921
13	Cameron Arroya, near Pueblo, Colo	1,900	1921
14	Sand Coulee, near DuBoise, Wyo	515	1934
15 [G]	Dry Creek, near San Angelo, Tex	1,760	1936
16 [L]	Devil's Canyon, above San Gabriel Dam #2, Calif	1,493	1938
17 [J]	San Antonio Creek, near Claremont, Calif	710	1938
18	Little Red Creek, Circle, Wyo	358	1934
19 [G]	Alazon Creek, San Antonio, Tex	1,497	1921
20	Willow Creek, near Heppner, Oreg	1,800	1903
21	Pinal Creek, near Globe, Ariz	560	1904
22	Burro Canyon, Madrid, Colo	852	1925
23 [J]	Tehachapi Creek near Tehachapi, Calif	704	1932
24	Crow Creek, near Cheyenne, Wyo	251	1924
25 [H]	Granada Creek, above Granada, Colo	886	1935
26 [J]	Sergeant Major Creek, Okla	1,450	1934
27 [J]	East Quartermaster Creek, Okla	1,320	1934
28 [J]	Nine Mile Creek, Okla	860	1934
29	Ysabel at Grande, Calif	395	1916
30	Rock Creek, near Pueblo, Colo	913	1921
31	Kiowa Creek, at Elbert, Colo	725	1935
32 [J]	North Fork of Skokomish, Hoodsport, Wash	389	1933
33 [A]	East Fork of James, Old Knoxville, Tex	1,730	1932
34	Wynoochie, Oxbow, Wash	277	1935
35 [G]	East Fork of Frio River, near Leaky, Tex	1,190	1932
36	Bull Run at Reservoir, Oreg	203.9	1931
37	Soleduck at Fairholm, Wash	238.5	1917
38	Sultan, at Sultan, Wash	279.5	1921
39	San Jacinto River, San Jacinto, Calif	417	1927
40 [J]	West Quartermaster Creek, Okla	640	1934
41 [G]	Johnson Creek, near Ingram, Tex	1,240	1932
42	South Fork of Stilaquonish, Granite Falls, Wash	223	1932
43 [H]	Kiowa Creek, above Kiowa, Colo	917	1935
44	Willow Creek, Morgan, Oreg	288	1903
45	Siletz, near Logsden, Oreg	270.7	1921
46 [H]	Mouth of Bijou, by mouth of Wilson Creek, Colo	488	1935
47 [G]	Salado Creek, Salado, Tex	965	1921
48 [G]	Seco Creek, 7 miles above D'Hanes, Tex	1,500	1935
49 [A]	Custer Creek, northeast, Miles City, Mont	135	1938
50	Turquillo Creek, Mora Valley, N. Mex	100	1904
51	Baker, near Concrete, Wash	200	1917
52 [H]	Kiowa Creek, north of Kiowa, Colo	578	1935
53	Cove Creek, at Phoenix, Ariz	125	1904
54	Siletz, at Siletz, Oreg	200	1921
55	Bear River, near Van Trent, Calif	336	1907
56 [J]	West Bijou Creek, Byers, Colo	580	1935
57	Mora River, at Weber, N. Mex	94	1904
58 [A]	Beaver Creek, Wibaux, Mont	106	1933
59	Skykomish River, near Index, Wash	160	1917
60 [G]	Tenaha Creek, near Joaquin, Tex	313	1933
61 [G]	West Fork Nueces River, near Brackettville, Tex	1,440	1935
62	Queets, near Clearwater, Wash	220	1935
63 [J]	San Luis Rey, Bonsall, Calif	250	......
64 [G]	Guadalupe River, Kerrville, Tex	344	1932
65 [G]	Jim Ned Creek, near Brownwood, Tex	280	1932
66	Lewis River, near Ariel, Wash	176	1933
67 [G]	Guadalupe River, near Comfort, Tex	19.9	1932

L—Los Angeles County Flood District Report; March 2, 1938.

J—"Maximum Stream-Flow with Reference to Flood Formulas," by C. S. Jarvis, Transactions American Geophysical Union, 1937.

G—"Major Texas Floods of 1936"; Geological Survey Water-Supply Paper #816.

H—"Rainfall and Run-off in Colorado," by M. C. Hinderlider; Engineering News Record, August 13, 1936.

A & B—From Compilations by C. S. Jarvis, derived mainly from U. S. Geological Survey Records.

All other recordings were taken from compilations by R. L. Lowry, "Floods in Texas," Transactions American Geophysical Union, 1937.

BOOK REVIEWS AND ABSTRACTS
By Phoebe O'Neall Faris

FLUID MECHANICS FOR HYDRAULIC ENGINEERS. By Dr. Hunter Rouse. New York and London. 1938.

In this, his new book, Dr. Rouse gives a clear presentation of the development of fluid mechanics, and shows the application of the modern theories and data to practical problems; it is apparent that he seeks thereby to convince the hydraulic engineer that there is much to be gained by giving heed to rational methods of analysis and research.

Dr. Rouse has been a member of the staff of the Soil Conservation Service cooperative hydraulic laboratory at the California Institute of Technology, Pasadena, Calif., almost since its inception in 1935. At the time this book was published he held the grade of assistant soil conservationist in the section of sedimentation studies, but since that time he has been promoted to the grade of associate hydraulic engineer. Although Dr. Rouse has spent much of his time on the study of theories of suspension and transportation of sediment as related to flood turbulence, he has taken an active part in the planning and operation of many other studies that are being made at the laboratory.

For about 30 years there has been a trend to bring together the theoretical or mathematical hydrodynamics and the so-called hydraulics which was based almost entirely on experiments. During the development of theoretical hydrodynamics in the second half of the last century, contact with reality and with practical engineering problems receded more and more into the background. This was due to the fact that in this so-called classical hydrodynamics everything was sacrificed to logical construction, and results could not be obtained unless deduced from the basic equations. Yet, in order to overcome the mathematical difficulties, these equations were simplified in a manner which often was not permissible even as an approximation.

On the other hand, the hydraulics which tried to answer the multitudinous problems of practice became gradually disintegrated into a collection of unrelated problems. Each individual question was solved by assuming a formula containing some undetermined coefficient and then determining these by experiments. Each problem was treated as a separate case, and there was lacking an underlying theory by which the various problems could be correlated.

The rapid development of aeronautics, and the application of aerodynamic principles to hydraulics and other branches of fluid mechanics, are mainly the results of pioneer work during the last fifteen years by Prandtl, Nikuradse, and Von Karman. These recent studies, which are based on mathematical hydromechanics, have been presented in several recent books on fluid mechanics.

Although the subject matter of Dr. Rouse's volume is of an advanced nature which is perhaps beyond the grasp of the reader lacking a foundation in elementary hydraulics, the book will be of considerable value in bed-load studies as carried on by the sedimentation and river hydraulic investigations section of the Soil Conservation Service.

As an introduction to his text the author briefly discusses dimensional analysis, the powerful mathematical tool of research. The remainder of the book is divided into three parts. Part I deals with the fundamentals of hydromechanics and it is here that the elementary principles and generalized equations of flow are discussed. Irrotational motion and conformal mapping—both valuable aids in solving complex flow problems—are presented in two separate chapters and with considerable thoroughness. This is a great advantage to Dr. Rouse's readers, as these subjects are not treated completely in contemporary books.

Part II contains material which is perhaps of more interest to the practicing engineer. The modern conceptions of fluid turbulence are treated in great detail and illustrated by experimental data. The problems of open-channel flow are uniquely treated and illustrated with experimental data much of which was observed by the author. The problem of transportation of sediment, which is of great importance in soil conservation studies, is also discussed.

Part III deals with the problems of the mechanics of wave motion, and here again is an important subject which is more completely treated than in contemporary books.

A few of the physical properties of water and some other common fluids are given in the Appendix.

EQUIPMENT PROBLEMS

(Continued from p. 182)

Fear of farmers as to difficulties in operating implements for erosion-control practices, and the inconvenience of changing farming systems are probably the greatest deterrents to a widespread adoption of the measures. These fears can be dispelled only by proving that the necessary practices do not work a hardship and by showing how to minimize the inconvenience caused by changing the farming system.

Undoubtedly there are many opportunities to increase the erosion-control value of the tillage practices by modifying them, or by developing new ones which can be more easily carried out by the farmers than those now commonly used, perhaps to the extent that there will be an actual decrease in the cost of performing the farm operations.

The development of more efficient methods through modification of the tillage practices can be accomplished only by an organized study of the problems. Such a study would serve not only as a means of developing more efficient technique in the use of present equipment, but would also be a means of determining which of the available types are most suited to operation under the varying conditions. Minor modifications which would make the various units more suitable to specific uses would also be developed. Any deficiencies in existing types would be brought to light, and this would permit manufacturers to make necessary adjustments in future models and to develop new equipment, whenever an economically justified need exists.

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